

TEENAGE CLUMSINESS: DOES IT EXIST?

A Thesis Submitted to the College of

Graduate Studies and Research

In Partial Fulfillment of the Requirements for the

Degree of Master of Science

In the College of Kinesiology

University of Saskatchewan

Saskatoon

By

Emily van der Kamp

PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for a copy of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis.

Requests for permission to copy or to make other use of material in this thesis in whole or part are addressed to:

Dean of the College of Kinesiology

University of Saskatchewan

87 Campus Drive

Saskatoon, Saskatchewan

S7N 5B2

DEDICATION

My family near and far

ACKNOWLEDGMENTS

Joan Perillat for the many companionable hours of “getting stuff done” at cafés.

My supervisor Dr. Adam Baxter-Jones for his time and support and my committee Lauren Sherar, Alison Oates and Doug Hillis for all their feedback and help.

Joel Lanovaz for his help with figuring out how to measure and analyze the endpoint matching task and John Nixon for helping me with statistics.

Leonard Lewko and Terrol Russell for allowing me to collect data with their athletes, and a special thank-you goes to all the athletes who participated in my study, their patience and focus was much appreciated.

ABSTRACT

Adolescence is characterized by systematic and dramatic physical and behavioural changes, the most noticeable physical growth is the rapid increase in stature marked by peak height velocity (PHV). Anecdotally, many people are aware that as youth pass through their adolescent growth spurt there is a perceived period of physical awkwardness; however, there is no scientific agreement as to whether a period of awkwardness associated with the adolescent growth actually exists. Previous research has focused on the development of general motor performance or gross motor coordination. Increases in strength during adolescence may mask the effect of a stage of adolescent awkwardness on general motor performance tasks. To detect adolescent awkwardness it is necessary to measure either performance of skills that specifically do not depend on strength, or body awareness. The purpose of this study was to investigate whether female adolescents' awareness of their body size and movement was influenced by biological maturation, and whether adolescent awkwardness could be detected in performance of sport specific skills independent of strength. An endpoint matching task was used to measure awareness of foot position in space by measuring the distance (mm) between a reference and matching endpoint position (endpoint matching error (EME)) with eyes either open or closed. The Johnson wall volley and a ball juggling task were used to measure soccer specific skill and coordination. Thirty six female youth soccer players, aged 10-14 years, were recruited. Age at PHV was predicted from measures of age, height, leg length and weight. Three groups were identified: pre-PHV (n=6), PHV (n=5) and post-PHV (n=25). Mean group differences were assessed using ANOVA. It was found that when the endpoint matching task was performed with eyes open there was no significant difference in mean EME between groups ($p > 0.05$). With eyes closed the PHV group performed worse than the pre-PHV and post-PHV groups. The Post-PHV group significantly ($p < 0.05$) decreased their EME (22.2 ± 13.9) compared to the PHV group (32.8 ± 17.6) but no difference was found with the Pre-PHV group (27.5 ± 15.7). On the wall volley test the Post-PHV group performed significantly ($p < 0.05$) better compared to the PHV group but not the Pre-PHV group. The Post-PHV group performed significantly ($p < 0.05$) better on the ball juggling task compared to both the Pre-PHV and the PHV groups. In conclusion, the results suggest that in the year around PHV body awareness, as measured by EME, may plateau or decrease and that soccer skill performance plateaus. This plateau or decrease in body awareness and soccer skills involving coordination is likely temporary; participants in this study who were > 6 months past PHV had significantly better body awareness and soccer skill performance than those participants who were within 6 months of PHV. The results from the endpoint matching task also indicate that a measure of body size and movement awareness has the potential to be used to measure changes in body awareness during the adolescent growth spurt. The results of this study suggest that teenage clumsiness could exist. However, a definitive study with larger maturity groups followed over time is required to confirm this statement.

CONTENTS

PERMISSION TO USE-----	i
DEDICATION -----	ii
ACKNOWLEDGMENTS-----	ii
ABSTRACT -----	iii
CONTENTS-----	iv
FIGURES-----	vi
TABLES -----	vi
APPENDICES -----	vi
CHAPTER 1-----	1
1.1 Introduction -----	1
1.2 Review of the Literature-----	2
1.2.1 Growth and Development:-----	2
1.2.2 Biological maturation-----	4
1.2.2.1 Skeletal age-----	5
1.2.2.2 Secondary sex characteristics-----	5
1.2.2.3 Prediction of age of PHV -----	6
1.2.3 Adolescent Growth-----	6
1.2.4 Adolescent Awkwardness -----	8
1.2.4.1 Evidence of continuous improvement in motor performance throughout adolescence -----	9
1.2.4.2 Evidence of a plateau in motor performance during adolescence -----	11
1.2.5 Sensorimotor function during adolescence-----	12
1.2.6 Strength and motor performance during adolescence -----	13
1.2.7 Body schema-----	14
1.2.8 Body schema and growth -----	15
1.2.9 Proprioception -----	16
1.2.9.1 Measuring proprioception and body awareness-----	16
1.2.10 Sport specific skills-----	17
1.2.11 Summary-----	17
1.2.12 Purpose and hypotheses-----	17

CHAPTER 2-----	19
2.0 Methods:-----	19
2.1 Study Design:-----	19
2.2 Measurement procedures-----	20
2.2.1 Soccer & sport background questionnaire-----	20
2.2.2 Biological Maturity-----	20
2.2.3 Soccer skill-----	20
2.2.4 Endpoint matching task-----	21
2.3 Statistical analysis-----	25
CHAPTER 3-----	26
3.0 Results-----	26
3.1 Descriptive statistics-----	26
3.2 Soccer skills-----	27
3.3 Endpoint matching task-----	28
CHAPTER 4-----	31
4.0 Discussion-----	31
4.1 Endpoint matching tasks-----	32
4.2 Soccer tasks-----	33
CHAPTER 5-----	35
5.0 Conclusion-----	35
5.1 Limitations-----	35
5.2 Future directions-----	36
REFERENCES-----	37
APPENDIX A: PARENT/GUARDIAN INFORMATION AND CONSENT FORM-----	43
APPENDIX B: PARTICIPANT INFORMATION AND ASSENT FORM-----	47
APPENDIX C: DATA COLLECTION FORM-----	51
APPENDIX D: QUESTIONNAIRE-----	52

FIGURES

FIGURE 1.1 Distance (cm) and velocity (cm/yr) of the Count de Montbeillard's son's growth in stature from birth to age 18.....	3
FIGURE 1.2 Four postnatal growth curves: (1) Lymphoid, (2) Neural, (3) General, (4) Genital presented as a percentage of total growth (Scammon, 1930).....	4
FIGURE 1.3 Velocity curves of growth in leg length and sitting height in boys and girls from the Harpenden growth study (Tanner, Whitehouse, Marubini, & Resele, 1976).....	7
FIGURE 2.1 Example of grid and endpoint positions A, B, and C used for endpoint matching task for right footed participants.	22
FIGURE 2.2 Photos from a left footed participant performing the endpoint matching task. a) Grid with + at position C, b) Reference endpoint position, c) Trial endpoint position.....	23
FIGURE 2.3 Finding X, Y coordinates of marker on participant's toe using ImageJ.	24
FIGURE 2.4 Endpoint matching error (EME) determined from difference between the reference and matching endpoints.	25
FIGURE 3.1 Comparison of maturity groups by wall volley performance.	27
FIGURE 3.2 Comparison of maturity groups by ball juggling performance	27
FIGURE 3.3 Comparison of maturity groups by eyes open and closed EME.	30
FIGURE 3.4 Comparison of maturity groups by difference between.....	30

TABLES

TABLE 3.1 Mean growth measures and amount of soccer training grouped by biological maturity based on months from predicted age of peak height velocity (PHV).	26
TABLE 3.2 Mean EME (distance between reference and trial foot locations) with eyes open, eyes closed, and the difference between eyes open and eyes closed for each of the 3 maturity groups.	28

APPENDICES

Error! Reference source not found. ----- Error! Bookmark not defined.	
PARENT/GUARDIAN INFORMATION AND CONSENT FORM-----	43
PARTICIPANT INFORMATION AND ASSENT FORM-----	47
DATA COLLECTION FORM-----	
511	
QUESTIONNAIRE-----	
522	

CHAPTER 1

1.1 Introduction

Adolescence is a time of change and growth, it is characterized particularly by a period of rapid growth in height. The point of the most rapid growth in stature during adolescence is peak height velocity (PHV). Peak growth in muscle size and strength occur between PHV and 1 year after PHV (Tanner J. M., 1990). Other changes in physiological variables include increases in aerobic and anaerobic capacity (Tanner J. M., 1990). The term “adolescent awkwardness” is used widely throughout the literature (Beunen & Malina, 1988; Butterfield, Lehnhard, Lee, & Coladarci, 2004; Davies & Rose, 2000; Isaacs, Pohlman, & Hall, 2003; Lloyd & Oliver, 2012; Philippaerts, et al., 2006; Quatman-Yates, Quatman, Meszaros, Paterno, & Hewett, 2012; Tanner J. M., 1990; Visser, Geuze, & Kalverboer, 1998) yet there is no consensus on how (and if) a stage of adolescent awkwardness can be measured (Quatman-Yates et al., 2012). Methods to detect and quantify adolescent awkwardness have included fine and gross motor tasks as well as sport-specific skill performance (Butterfield et al., 2004; Davies & Rose, 2000; Visser et al., 1998). Some studies have shown a decline in performance around PHV (Visser et al., 1998), others have shown no decline (Butterfield et al., 2004; Davies & Rose, 2000), while still others have used adolescent awkwardness to explain why some adolescents seem to lose skill (Isaacs et al., 2003; Philippaerts et al., 2006). The wide range of methods used to detect and quantify “adolescent motor awkwardness” or “teenage clumsiness” may be the reason for the controversy in the literature over its existence.

The brain and sensorimotor system has to adapt to the rapid physical changes that occur during adolescence in order to accurately coordinate movements and interact with the environment (Quatman-Yates et al., 2012). The body schema is the brain’s representation of the size and proportions of the body and is used as a reference frame for constructing movement patterns (Berlucchi & Aglioti, 1997; Ivanenko, et al., 2011; Maravita & Iriki, 2004; Stamenov, 2005; Viel, Vaugoyeau, & Assaiante, 2009). During rapid growth, changes in limb length and body proportions may create a mismatch between the body schema and the actual size and proportions of the body. Throughout growth, body proportions change. For example: from infancy through to adolescence leg length increases relative to overall height, reaching the lowest ratio around PHV (Tanner J.M., 1990). PHV occurs between peak leg length growth and peak trunk length growth. After PHV is attained the trend of increasing leg length relative to overall height reverses as the trunk’s growth rate increases and leg length growth rate decreases (Tanner, Whitehouse, Marubini, & Resele, 1976; Tanner J. M., 1990). These changes may cause a disturbance to body schema which could contribute to a temporary plateau in the function of the sensorimotor system and provide an explanation for adolescent awkwardness.

The purpose of this study is two-fold. Firstly to explore the phenomenon of adolescent awkwardness by examining if female adolescent soccer player’s awareness of their body size and movement is influenced by maturity status. Secondly to test if adolescent awkwardness can be detected using sport specific skills.

1.2 Review of the Literature

Are teenagers really clumsy? As children become adolescents and hit a growth spurt they seem to lose sense of their body size. The trail of broken objects and spilt drinks may seem to be a testament to a loss of physical coordination and might also be cause for fear of injury or decline in sports skill. Parents and coaches alike have good reason to be concerned when their growing athletes appear to "shoot up so fast their brains can't keep up" (BBC, 2014). Although teenage clumsiness is perceived to be a real phenomenon (Nottingham Post, 2012; Reynolds, 2011; Schuster & Ashburn, 1992; Tanner, 1990) it has proven to be an elusive quality to measure (Quatman-Yates et al., 2012). Sports science research has rarely documented it and there is no scientific agreement as to whether it actually exists or not. In a systematic review of sensorimotor function during adolescence, Quatman-Yates et al. (2012) speculate that teenage clumsiness or 'adolescent motor awkwardness' may be related to changes in sensorimotor mechanisms during rapid growth; however, they found that the scientific evidence thus far is inconclusive. As indicated previously, adolescence is a time of rapid growth. The physical changes occurring at this time, particularly in overall height and limb length, may disrupt teenagers awareness of the own bodies. Clumsiness during adolescence may be difficult to measure but that doesn't mean it doesn't exist and doesn't impact youth's everyday lives and athletic development.

1.2.1 Growth and Development:

In the simplest terms, growth reflects an increase in cell number, size or intercellular substances (Tanner J. M., 1990) whereas development is both biological and behavioural. Biologically development is defined as "a series of changes in the state of a cell, tissue, organ or organism" which "gives rise to the structure and function of living organisms." (Brooker, Widmaier, Graham, & Stiling, 2008). Behaviourally it refers to development of psychosocial competence as well as the development of physical literacy or motor competence (Balyi, Cardinal, Higgs, Norris, & Way, 2005; Orr & Ingersoll, 1988). In the growth and development literature "growth" commonly refers to increase in size from conception to adulthood, with the adult state being the end target (Malina & Beunen, 1996); however, most body systems do not reach a completely static size or state in adulthood but fluctuate in response to various internal and environmental factors (e.g. diet, exercise and disease). There are two types of growth: the growth which can occur at any stage of life (e.g. changes in horizontal size) and the growth which is a progression towards the adult state. Some aspects of the body can fluctuate in size or state more than others (e.g. muscle and fat mass vs bone length, horizontal vs vertical size) and occur throughout the lifespan. When measuring growth which is a progression towards the adult state it is necessary to be careful which body systems are used and how measurements are performed.

Growth can be measured in both rate (tempo) and distance (timing). Rate of growth is how quickly size is increasing, it is size/time. Distance is absolute size at any point in time; it is an accumulation of all the preceding growth. Distance of growth can be found with a single measurement occasion such as in a cross-sectional study whereas detecting rate of growth usually requires longitudinal data, meaning more than one measurement point over time (Malina et al., 2004). The earliest recorded longitudinal measurement of human growth was of the height of the Count De Montbeillard's son, measured every few months from birth to age 18. As shown in figure 1.1, the Count's son's growth is shown both as a distance curve (Figure 1.1a) and a velocity curve (Figure 1.1b).

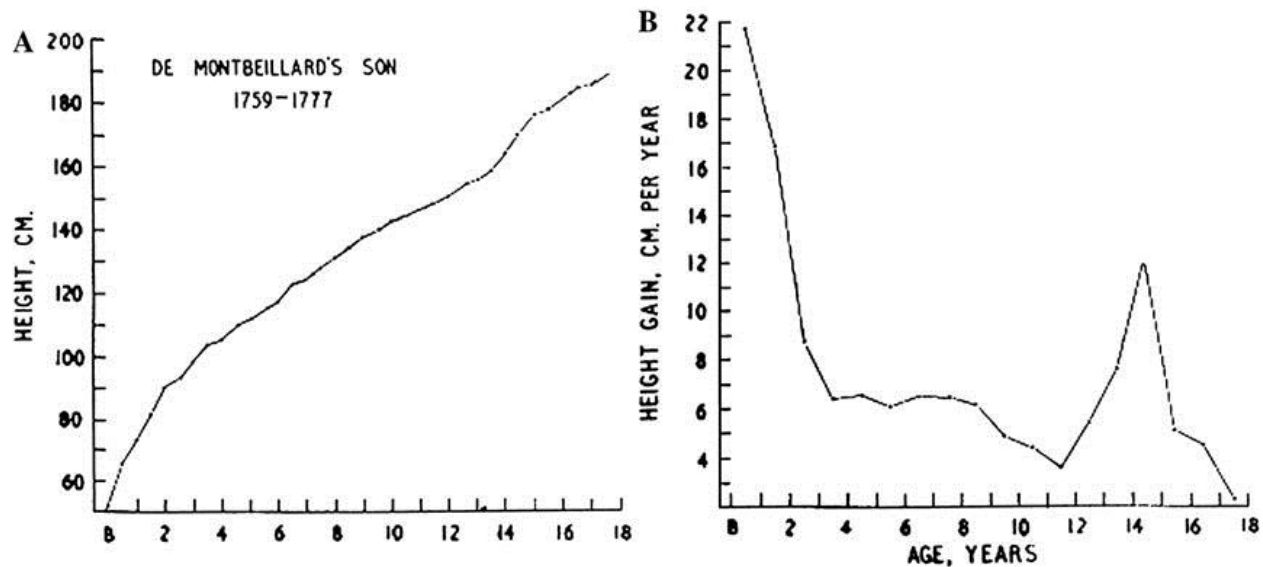


Figure 1.1 Distance (cm) and velocity (cm/yr) of the Count de Montbeillard's son's growth in stature from birth to age 18.
(Retrieved from <http://ejo.oxfordjournals.org/content/30/5/449/F7.expansion>)

All healthy children have growth spurts that follow the same pattern and sequence as observed in this original data set, though the timing and tempo may vary (Tanner J. M., 1990). The most accelerated period of postnatal growth in height in humans is during the first few years of childhood (figure 1.1b); by age 4 or 5 growth rate has decelerated from about 20cm/yr to about 5-7cm/yr. Growth rates stay at around 5-7cm/yr until the onset of puberty at about age 10 in girls and age 12 in boys (Tanner J. M., 1990). There is a slight deceleration in growth rate before the pubertal increase. During adolescence growth rate in height reaches an average of 9.0cm/yr at its peak in girls and 10.3 cm/yr at its' peak in boys (Tanner J. M., 1990). This peak in growth is called peak height velocity (PHV), it is used to represent the adolescent growth spurt. PHV itself is instantaneous and estimated: the average growth rate for the entire year around PHV is less than the estimated peak (Tanner J. M., 1990). In Figure 1b PHV can be seen to be occurring just after 14 years of age. Growth continues after PHV velocity occurs but the rate declines to 0 cm/yr as full maturity is reached around age 16 in girls and age 18 in boys (Tanner J. M., 1990). Boys grow an average of 7cm, 9cm and then 7cm in height during each of the 3 years respectively of their adolescent growth spurt, while girls grow 6, 8 and 6 cm in height during each of the 3 years respectively of their growth spurt (Tanner J. M., 1990).

The growth spurt in height is the most obvious, but other body tissues go through similar growth spurts as well. In 1923 Richard Scammon proposed that postnatal growth rates generally follow set patterns which can be represented by 4 different curves (Figure 1.2). These curves represent the growth of four different categories of body tissues from birth to age 20 relative to size at age 20 (Scammon, 1930). Muscle, fat and skeletal growth as well as body size on the whole all follow the general curve. The general curve has a sigmoidal shape because rapid growth occurs during early childhood and again during adolescence (Figure 1.1a).

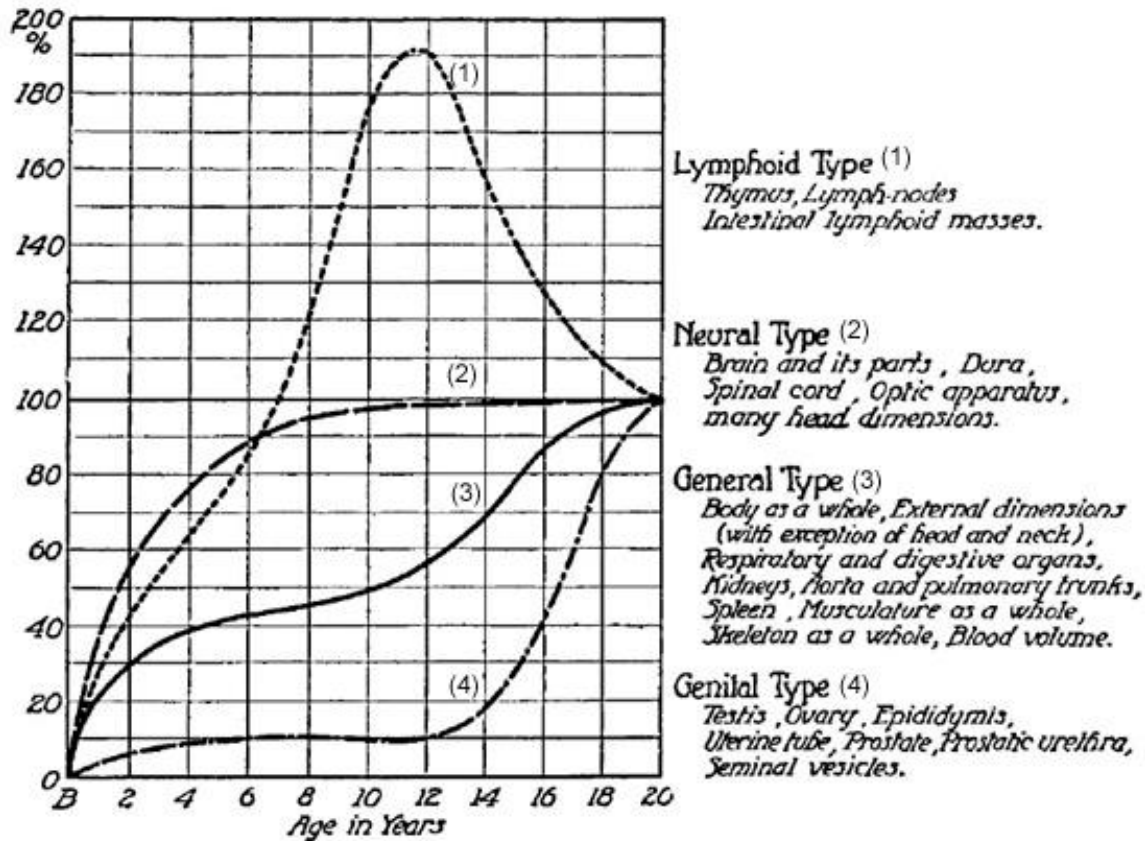


Figure 1.2 Four postnatal growth curves: (1) Lymphoid, (2) Neural, (3) General, (4) Genital presented as a percentage of total growth (Scammon, 1930).

1.2.2 Biological maturation

The pattern of growth, the shape of the growth curves, is generally the same between individuals although the chronological age at which different stages of maturity are reached and the rate of growth can vary considerably (Malina & Beunen, 1996). Youth of a given chronological age are not all at the same biological age. Chronological age is a child's age in years and months since they were born, whereas biological age reflects the stage a person is at in the progression to the physically mature state (Malina & Beunen, 1996). Children who have their adolescent growth spurt earlier than average are early maturers, whereas children who attain PHV later than average are late maturers (Tanner J. M., 1990).

There are a number of different ways of measuring biological maturation. Measuring change in height over time as the Count De Montbeillard did is a simple longitudinal method (Figure 1.1). Measuring longitudinally is very accurate but takes time and highest rate of growth, such as peak height velocity, can only be determined after it has occurred. Height is a better measure of biological maturation than fat deposition or increases in muscle size, it is also the most noticeable change resulting from childhood and adolescent growth. One of the best non-intrusive ways of determining biological maturity and rate of growth is by measuring height at regular intervals, the more often the better (Malina et al., 2004).

Using x-rays to determine skeletal age is the preferable method when it is necessary to determine biological maturity in a cross-sectional study or when it is important to know a person's biological age in the present and not retrospectively (Malina et al., 2004). Skeletal age is not a measure of peak height velocity; when PHV is the variable of interest it can be determined from serial height measurements or predicted using the equation developed by Mirwald, Baxter-Jones, Bailey, & Beunen (2002).

1.2.2.1 Skeletal age

Skeletal age is a strong representation of biological maturation in general. The skeleton is the framework for the body, providing structure for muscles, nerves, etc. (Klavora, 2012). Skeletal growth precedes growth of skeletal muscle, and it spans the entire growth period from birth through to adulthood (Malina, Bouchard, & Bar-Or, 2004).

All bones follow an irreversible process from cartilage to mature bone and these changes in individual bones and the skeleton as a whole occur in a continuous, definite order with a definite endpoint (Malina et al., 2004). These changes in skeletal maturation can be used to determine biological maturation both cross-sectionally and longitudinally. This is done by comparing x-rays of skeletal growth at the hand and wrist to previously identified age and sex reference standards such as in the Greulich-Pyle, Tanner-Whitehouse (TW2) or Fels methods (Malina et al., 2004). Skeletal maturation is a continuous measure of maturity status that spans from before birth to adulthood with high capacity for accuracy. Using hand and wrist X-rays is possibly the best method of determining biological maturity at any point in growth, however: it is expensive, requires trained observers to accurately interpret and compare the x-rays to the standards, and exposes youth to a small amount of radiation.

1.2.2.2 Secondary sex characteristics

The first overt sign of pubertal development is the appearance of secondary sex characteristics. These can be used to assess biological maturity but are only a meaningful measurement around adolescence (Baxter-Jones, Eisenmann, & Sherar, 2005). Secondary sex characteristics cannot be used to determine tempo or stage of growth before onset of puberty. Scammon's "genital type" curve (Figure 1.2) shows that growth of secondary sex characteristics does not begin until the start of puberty, around age 12. Assessing sexual maturation is inherently invasive of individual's privacy and may be embarrassing to both researchers and participants. There are a few different methods of assessing sexual maturity which have been used in growth studies. These methods are sex-specific and include examining genital development in boys, breast development in girls as well as pubic hair growth in both sexes. These methods all involve comparing to photographs or drawings of the stages of development. There are fewer markers of development to compare to than when using skeletal maturation; there are only 5 or 6 stages for each characteristic of sexual maturation and these stages are somewhat arbitrary and broad. This method is not very precise because both an individual at the beginning of a particular stage and an individual nearing the end of the same stage could be classified as at the same maturity. During adolescence maturity status can vary considerably between individuals of the same chronological age, maturation is happening quickly and so in order to catch the time point of change between stages it is necessary to do multiple measurements within a year. (Malina et al., 2004)

1.2.2.3 Prediction of age of PHV

As an alternative to skeletal age or the other methods mentioned above, Mirwald et al. (2002) developed a non-invasive measure of maturity. Somatic equations of anthropometric growth were developed which provide a relatively accurate (± 1 year 95% of the time) way to estimate the timing of PHV. These gender-specific multiple-regression equations can be used to predict age at peak height velocity (APHV) from chronological age, body mass, leg length and sitting height. These equations are particularly useful when peak height velocity, not just biological maturity, is the variable of interest. This is because it can be used to predict PHV in the present while with other methods PHV can only be determined retrospectively or not at all. It works because body proportions change during growth and there is a common sequence between the growth of the legs and the trunk (Mirwald et al., 2002). The legs grow before the trunk and so PHV occurs between peak leg growth and peak trunk growth (Tanner J.M., 1990). Measurements of sitting height and standing height can be used in combination with other variables to predict maturity offset.

1.2.3 Adolescent Growth

Adolescence is characterized by systematic and dramatic physical and behavioural changes, the most noticeable physical growth is the rapid increase in stature (marked by PHV at the beginning of the teenage years) (Beunen & Malina, 1988). Growth occurs from distal to proximal: the hands and feet growing first and then the legs and finally the trunk around 6 to 9 months after the legs (Tanner J. M., 1990). This sequence of growth means that peak velocity of growth in the legs occurs before PHV and peak velocity of growth in the trunk occurs after PHV (Beunen & Malina, 1988; Tanner et al., 1976). The ratio of sitting height to standing height changes a lot over the course of the adolescent growth spurt because leg length increases before trunk length (represented by sitting height). Growth in leg length occurs first so may be more noticeable to the growing adolescent than growth in sitting height but growth in sitting height continues for a longer period than growth in leg length and contributes more to the adolescent growth spurt as shown in figure 1.3 (Tanner et al., 1976).

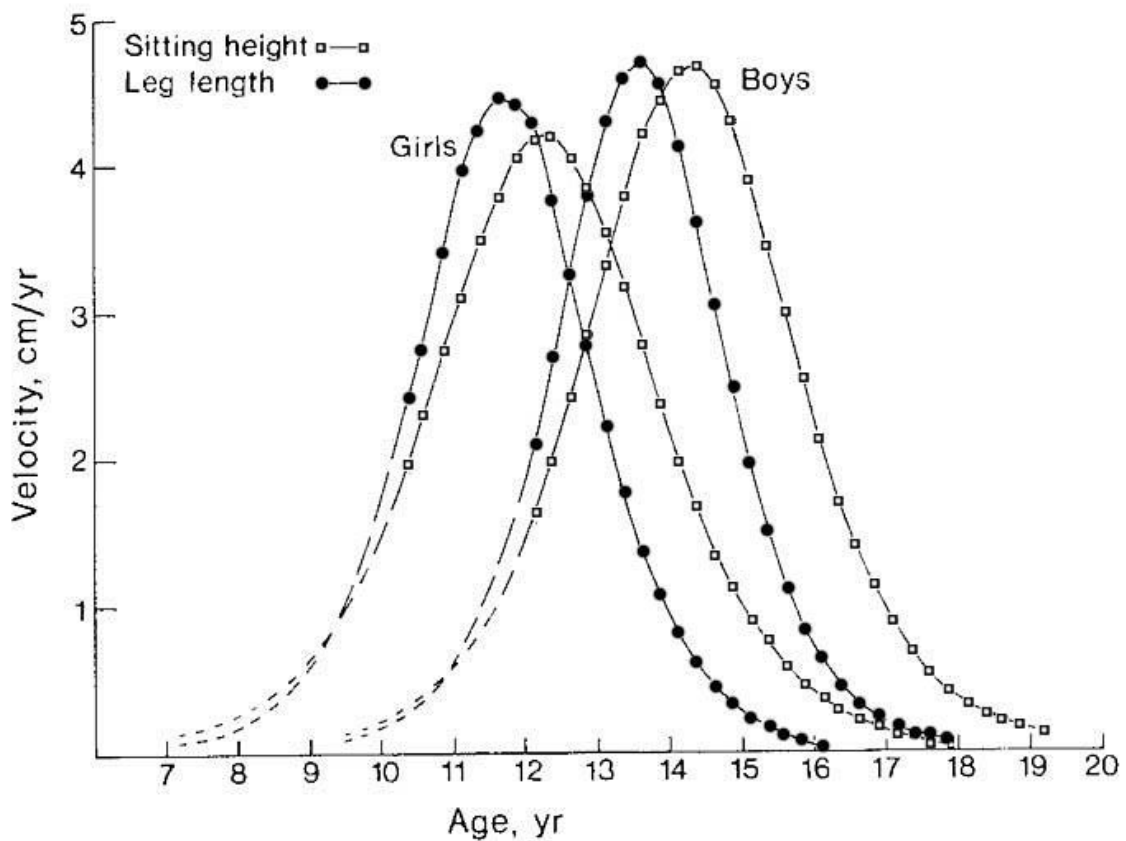


Figure 1.3 Velocity curves of growth in leg length and sitting height in boys and girls from the Harpenden growth study (Tanner, Whitehouse, Marubini, & Resele, 1976).

Puberty marks the onset of sexual maturation and is when the differences between the two sexes start to become more apparent. Boys end up taller than girls because they have both more years of pre-adolescent statural growth and higher rate of skeletal growth during adolescence (PHV is greater in boys and occurs 2 years after girls (Beunen & Malina, 1988; Tanner J. M., 1990)). Weight gain also accelerates during adolescence; peak weight velocity (PWV) occurs relatively late in growth from 0.2 to 0.9 years after PHV (Malina et al., 2004), which means that the ratio of height to weight changes throughout adolescence.

At the same time as growth in height and weight is accelerating in adolescence fat mass accumulation is decelerating (Tanner J. M., 1990). This deceleration is most prominent in the subcutaneous fat, particularly in boys. Subcutaneous fat accumulation on the limbs reaches a negative velocity in boys around the time of peak height velocity so that they actually lose some accumulated fat mass while in girls it only slows (Tanner J. M., 1990). The ratio of muscle tissue to fat tissue on the upper arms doubles in males during puberty (Thomas & French, 1985). In adulthood girls, on average, have higher fat mass than boys particularly subcutaneous fat mass (Tanner J. M., 1990).

Both boys and girls have a growth spurt in muscle during adolescence that peaks after PHV, around the time of peak weight velocity (Jones & Round, 2000), this peak in muscle growth is higher in boys than girls (Tanner J. M., 1990). Boys hit peak weight velocity (PWV) earlier in their adolescent growth than girls (around 0.2 to 0.4 years after PHV whereas girls hit peak weight velocity 0.3 to 0.9 years after PHV) because muscle mass contributes relatively more than fat mass to boys' weight than it does to girls' weight (Malina et al., 2004). The growth spurt in muscle size is accompanied by a spurt in strength (Malina et al., 2004). Static strength increases in boys peaks about 1-1.5 years after PHV (Froberg & Lammert, 1996). Boys have a spurt in strength that is larger than that accounted for by the increase in muscle size, (Jones & Round, 2000) particularly in the upper body (Malina et al., 2004). This indicates that hormone changes during growth result in increased muscle signalling, contractility, or efficiency; the increase in testosterone levels seen in boys around puberty explains the difference between boys and girls in muscle strength when body size is accounted for (Jones & Round, 2000). The difference between boys and girls in strength development after puberty may be more present in upper than lower body strength (Jones & Round, 2000).

1.2.4 Adolescent Awkwardness

As indicated above, early adolescence is a time of rapid physical growth. It also represents a period of social, cognitive and behavioural maturation (Orr & Ingersoll, 1988). Adolescence and the adolescent growth spurt in height is sometimes assumed to be associated with a certain amount of clumsiness (Reynolds, 2011; Nottingham Post, 2012). Clumsy as defined in the Oxford English dictionary (2014) is: "awkward in movement or in handling things" or "done awkwardly or without skill". Clumsiness during adolescence could have physical origins, psychological origins or both (Orr & Ingersoll, 1988). Physically, adolescents might not have a good sense of the changing proportions of their body or how long their limbs have become (Tanner J. M., 1990). Psychologically, they may feel awkward in their rapidly changing bodies or in their changing role in society and this may manifest itself in how they carry themselves, in their posture and how they use their limbs (Orr & Ingersoll, 1988). This research and discussion will focus on the possible physical/physiological origins of clumsiness.

It is common perception that kids sometimes become clumsy when they grow rapidly. "Sudden growth spurts" (Nottingham Post, 2012) is the explanation given in news articles and online forums for the "physically gawky stage during the so-called tween years, beginning around age 11 or 12" (Reynolds, 2011). This same explanation is given in sports science textbooks: for example, "the adolescent may be awkward in gross-motor activity—it takes time to get used to one's new body." (Schuster & Ashburn, 1992). Tanner (1990) suggested that there is a period of about 6 months after trunk growth (the last body segment to increase in length), before the muscles have reached full size and strength, which may bring temporary balance problems. There is concern that this clumsy stage, with the resultant risk of banging into things, falling and/or sending surrounding objects flying, is accompanied by increased risk of injury (Reynolds, 2011). Research has shown that adolescence is indeed a time of increased fracture risk, although whether this is due to physical activity patterns or bone strength is unclear (Khosla, et al., 2003). There is a widely accepted assumption that teenagers are clumsy because they are growing rapidly and that they shoot up so fast their brains can't keep up (BBC, 2014). Teenage clumsiness makes

a lot of sense at face value; however, there is probably more consensus on the existence of teenage clumsiness amongst the general public than in the scientific literature.

The term “adolescent awkwardness” is used in the research literature to refer to this clumsy stage of growth. Although the term exists it isn’t backed by a lot of evidence; there is controversy as to whether teenage clumsiness as a phenomenon actually exists, regardless of whether it has a psychological or physiological basis. A search of the literature reveals that it isn’t easy to pinpoint. The concept of adolescent awkwardness is built on without a lot of evidence that it does indeed exist, and despite recent scientific evidence that it does not. Adolescent awkwardness was been described in the scientific literature as early as 1922 and persists to the present day (Homburger as cited in Beunen & Malina, 1988). The assumption that this phenomenon does exist is well embedded in sports science textbooks (Beunen & Malina, 1988; Tanner J. M., 1990; Schuster & Ashburn, 1992), research literature (Philippaerts, et al., 2006; Isaacs et al., 2003) and sports policy (Balyi et al., 2005).

The Canadian long term athlete development (LTAD) model refers to an awkward period during early adolescence around PHV when the extremities grow before the trunk causing changes in body proportions. During this period “athletes may appear gangly and lose control of their extremities” (Balyi et al., 2005). Lloyd & Oliver (2012) question the theory of “windows of opportunity” for training adaptations suggested in the LTAD model but accept without question that adolescent awkwardness exists (Balyi et al., 2005). They emphasize the need for coaches to monitor growth rates and be aware of potential decreases in performance due to the “rapid gains in limb length during adolescence” (Lloyd, R. & Oliver, 2012).

Adolescent awkwardness makes sense: “the adolescent may be awkward in gross-motor activity—it takes time to get used to one’s new body.” (Schuster, 1992). Yet, findings from past research investigating “adolescent awkwardness” are largely inconsistent with the widely held assumption that the phenomenon exists. Many studies of motor proficiency, such as sprinting, jumping or throwing, and sport specific skill have found that performance generally improves continuously throughout childhood and adolescence (Butterfield et al., 2004; Davies & Rose, 2000; Philippaerts, et al., 2006; Visser et al., 1998; Isaacs et al., 2003).

1.2.4.1 Evidence of continuous improvement in motor performance throughout adolescence

Physical literacy has been defined as the ability to move with competence and confidence (Physical Health and Education Canada, 2015) and is required to develop proficiency in sport specific skills (Balyi et al., 2005). Physical literacy encompasses fundamental movement skills, such as running, kicking a ball or balancing, which are the basis for a number of sport specific skills (Balyi et al., 2005). It is suggested that physical literacy should be established before adolescence (Balyi et al., 2005) yet around PHV there is a period of ‘adolescent awkwardness’ during which some movement competence appears to be lost (Beunen & Malina, 1988; Lloyd & Oliver, 2012; Isaacs et al., 2003; Tanner J. M., 1990; Visser et al., 1998).

The following are three different studies which addressed adolescent awkwardness and found evidence of continuous improvement in motor performance throughout adolescence.

Malina et al. (2005) compared the contribution of experience, body size and maturity status to performance of sport specific skill in soccer players aged 13-15. Age, experience, body size and stage of puberty explained very little (8-21%) of the variance in performance on 4 of the 6 soccer tasks. The older, more mature players performed only slightly better than their peers on the soccer tasks. Chronological age, years of experience, and biological maturity (measured by secondary sex characteristics) explained a larger portion of the variance in speed and power than the variation in soccer specific skills. These results suggest that if there is a stage of adolescent awkwardness it may be masked by the increases in speed and power with increased age, experience and maturity.

Butterfield et al. (2004) conducted a 9 month longitudinal study comparing speed and power in boys and girls between the ages of 11 and 13. Measurements of 20 yard sprint speed and vertical jump height (measure of power a.k.a. explosive strength) were taken 3 times throughout the school year. Height, weight and sex were taken into consideration but no measure of biological maturity or physical training was included. On average jump height and running speed improved in both boys and girls. Although performance decreased in some children between September and May this was attributed to limited physical activity during the winter. The correlation between performance on the initial measurement occasion and amount of improvement was opposite for running and jumping. The children who had the slowest times in the 20 yard sprint initially improved the most out of all the children in running whereas those who had the highest vertical jumps initially improved the most out of all the children in jumping. The overall increase in performance with time in both boys and girls provides some evidence against a stage of adolescent awkwardness. However, not all adolescents hit their growth spurt at the same time and so although some may have had their growth spurt during the 9 month collection period not all would have. This study shows that on average there is an increase in running and jumping ability in boys and girls between the chronological ages of 11 and 13. In order to better consider the impact of the adolescent growth spurt they would have needed to include a measure of biological maturity. Also, running speed and jumping height are likely not the best measures of changes in motor control ability or coordination throughout adolescence when strength is increasing.

Davies & Rose (2000) conducted a cross-sectional study comparing motor performance of youth in 3 pubertal developmental stages. Sixty youth were included in the study with 10 males and 10 females in each of 3 pubertal groups (prepubertal, pubertal, and postpubertal). They were classified into these groups using the Pubertal Maturation Observation Scale (PMOS) and their parents' answer to whether they had hit their pubertal growth spurt. The youth performed 13 motor tasks adapted from the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP), 8 of which were novel tasks not previously included in research studies: the goal was to include tasks that were not limited to strength and speed. The participants were recruited from a variety of groups (elementary public and private schools, high school psychology classes, scout groups, and children of faculty at a state university) and amount of physical activity/training was not controlled for. They found a difference in motor performance between girls and boys but no evidence of a plateau in motor performance at the pubertal stage; there was continuous improvement in motor performance from the prepubertal stage to the postpubertal stage. These results also give evidence against a stage of adolescent awkwardness.

1.2.4.2 Evidence of a plateau in motor performance during adolescence

A few studies have found evidence of “adolescent awkwardness” or teenage clumsiness but the evidence is not strong.

A 2013 update which provided normative data of vertical jump standards for children aged 7 to 11 years found evidence of performance decline with age in early adolescence. In compiling the update Isaacs, Pohlman & Hall (2003) found that top performing 10 year old boys (100th centile for jump height) could jump higher than the top performing 11 year old boys. They attributed this phenomenon to “adolescent awkwardness” as defined by Payne & Isaacs (2002): “a period during the growth spurt (peak height velocity) that is accompanied by a temporary disruption in motor performance”.

Similar to the studies showing no evidence of adolescent awkwardness Visser et al. (1998) conducted a study to examine the “relationship between physical growth, the level of activity and development of motor skills in adolescence.” This was a 2.5 year longitudinal study following a group of 31 boys from age 11.5 till age 14. The boys were divided into two groups; those diagnosed with Developmental Coordination Disorder (DCD) (American Psychiatric Association, 1994) and those without. Their velocity of growth (height, weight and height-weight ratio) was measured at regular intervals, aligned by onset of adolescent growth spurt and compared to their performance on the Movement Assessment Battery for Children (Movement ABC). Their level of activity was estimated with a questionnaire about activities that relate to the tasks in the Movement ABC. They found that while some boys do experience a decrease in performance on tasks that require sensorimotor coordination, it was the children with adequate skills whose motor performance was more affected by the adolescent growth spurt than the children who were classified into the DCD group. It could be speculated that the reason those who are most skilled are more likely to be affected by rapid growth is that they expect to be able to perform well without much focus and are used to relying heavily on their inherent knowledge of their body, compared to children with DCD who are probably well aware that they are not skilled at motor performance tasks. When they grow rapidly there may be a period of time during which their inherent knowledge of their bodies is inaccurate and this literally trips them up

Philippaerts et al. (2006) analyzed data from the Ghent Youth Soccer project, a 5 year mixed longitudinal study which followed male soccer players between the ages of 10 and 16 years. They compared male soccer players and the general adolescent male population on development of physical performance relative to PHV. Physical performance/fitness was assessed using the Eurofit test (including measures of balance, flexibility, strength and speed) and soccer-specific performance tests (focusing on running speed, explosive strength and anaerobic capacity). In addition to height and weight, skeletal maturity was measured using the TW2 method. Measurements were conducted yearly but velocities were estimated for 6 month intervals using the modified non-smoothed polynomial method. They found very little difference in velocity of improvement between soccer players and the general population. Performance on most of the tests improved continuously and the velocity of improvement reached a peak around PHV. However they found a decline in 30m dash performance before PHV that they attributed to adolescent awkwardness. Similar to previous studies discussed above, it was the boys who were already good performers who showed the decline in performance.

1.2.5 Sensorimotor function during adolescence

A recent review article by Quatman-Yates et al. (2012) on sensorimotor function during adolescence acknowledges the discrepancy between what is assumed about adolescent awkwardness and what has been shown: "Although adolescent motor awkwardness and increased injury susceptibility have often been speculated and researched, studies regarding adolescent regressions in motor control have yielded inconsistent conclusions." The authors suggest that adolescent awkwardness may be explained by temporary delays or regressions in certain sensorimotor mechanisms. Sensorimotor function is the system of sensory feedback pathways, central nervous system processing and motor nerve signals that allows a person to perform motor actions. These systems may not be fully mature when the adolescent growth spurt occurs and so clumsiness ensues (Quatman-Yates et al., 2012). Past research on adolescent awkwardness has widely varying conclusions and this may be because studies have looked at motor skill performance in general rather than at the specific sensorimotor motor mechanisms (Quatman-Yates et al., 2012). The review focused on answering two questions: 1) "Which sensorimotor mechanisms are not fully mature by the time children reach adolescence?" and 2) "Is adolescence a period when children exhibit delays or regressions in sensorimotor mechanisms?" There has been plenty of research that helps to answer the first question but only a few studies address the second question.

The first question: "Which sensorimotor mechanisms are not fully mature by the time children reach adolescence?" is often examined through the study of postural control. Postural control is at the basis of all movement; good posture provides a stable base from which to execute other actions (Viel et al., 2009). Good postural control is particularly important for balance, coordination and injury prevention both in sports and moving around in everyday life (Ives, 2014). Children and adults use different strategies for maintaining standing balance suggesting that there are changes in postural control during or after adolescence (Viel et al., 2009; Mallau et al., 2010). Children rely more on visual cues over other somatosensory feedback for postural control than do adults. This makes sense given that the studies Quatman-Yates et al. (2012) reviewed also showed somatosensory (cutaneous and proprioceptive) and vestibular mechanisms are still developing during childhood, possibly into early adolescence (past age 11). Children rely more on what they can see around them to orient themselves in space than on somatosensory mechanisms. Early adolescents (around age 10-11) resemble adults in postural control when the task is simple but resemble children when the task is more challenging (Streepey & Angulo-Kinzler, 2002). As children mature into adults their somatosensory and vestibular organs become fully mature and they are better able to use this feedback about where the body is in space, so their reliance on vision for this information would logically decrease. However this review found that when a child is growing rapidly as they enter adolescence they may regress in their use of proprioception and they may temporarily rely more on vision for postural control (Viel et al., 2009). The theory for why this happens is that the rapid growth of PHV creates new postural challenges similar to those experienced by young children learning to stand or walk (Quatman-Yates et al., 2012).

Coordination generally improves throughout adolescence and this may be related to development in postural control as well as improvements in sensorimotor processing (Quatman-Yates et al., 2012). Good postural control underlies good coordination which is to say it underlies the ability to perform

actions in an efficient and effective manner (Ives, 2014). Coordination refers to how smooth and accurate limb and limb segment control is in performing motor actions and incorporates “speed, direction, muscular tension, timing and synergistic muscle recruitment” (Quatman-Yates et al., 2012). Coordination, particularly fine tuning of movement patterns, improves continuously throughout adolescence (Quatman-Yates et al., 2012). This was seen in: increased ability to isolate movement of individual body segments from accessory movements, improved synergy in muscle activation, improved segmentation of movement of body parts leading to smoother movement, and better ability to anticipate and prepare movements leading to faster movement time (Quatman-Yates et al., 2012). In answer to question 1, “Which sensorimotor mechanisms are not fully mature by the time children reach adolescence?” Quatman-Yates et al. (2012) found that specific sensorimotor mechanisms (such as somatosensory and vestibular) are still maturing when the adolescent growth spurt hits.

While not many studies addressed the second question: “Is adolescence a period when children exhibit delays or regressions in sensorimotor mechanisms?” those that did address it showed that it is possible that there are regressions in some sensorimotor mechanisms during the adolescent period (Kirschenbaum, Riach, & Starkes, 2001; Saavedra, Woollacott, & van Donkelaar, 2007). These regressions were both in proprioceptive sensitivity and in motor control. The regressions in motor control were in the form of changes in neuromuscular knee control during landing from a vertical jump (in adolescent girls but not boys) (Hewett, Myer, & Ford, 2004; Quatman, Ford, Myer, & Hewett) as well as regressions in postural control and hand-eye coordination which are seen around age 7-9 years (Kirschenbaum et al., 2001; Saavedra et al., 2007). Two studies included in the review “found regressions in motor control characterised by periods of ‘overcontrol’ in which children appear to sacrifice speed and variability in movement for the sake of accuracy and control” (Kirschenbaum et al., 2001; Saavedra et al., 2007).

1.2.6 Strength and motor performance during adolescence

Peak strength velocity occurs soon after PHV (Malina et al., 2004) therefore tests of motor performance carried out around PHV may be detecting an increase in strength with development rather than an increase in motor skill level per say. A lot of previous research has used vertical jump, sprinting or other tasks which are not independent of strength, to study changes in motor performance during adolescence (Butterfield et al., 2004; Isaacs et al., 2003; Philippaerts, et al., 2006). Even if a child has grown and their body schema no longer matches their body size they could be stronger and able to jump and run faster than before. Davies & Rose (2000) addressed this problem by including tests of coordination and fine motor skill that did not rely on lower body strength. However, even when strength is not a main factor, general tests of motor skill, such as those used in the BOTMP, may not be able to capture a regression in sensorimotor function during the adolescent growth spurt. Gross motor coordination may not be affected by the growth spurt and so it may be necessary to focus on more specific sensorimotor aspects of motor skill performance (Quatman-Yates et al., 2012).

Yet for adolescent awkwardness as a result of a plateau in specific sensorimotor mechanisms to be obvious to the general public it must also have a noticeable effect on every day motor tasks. A principle of scientific research is to minimize the influence of external variables as much as possible in order to establish a direct cause-effect relationship. There is something different about the conditions of motor

tasks performed in everyday life versus in a lab that must explain this dichotomy between research findings and common knowledge. It can be speculated that the reason for this dichotomy is that the lab eliminates the everyday environment which may be much more familiar and also more distracting. Adolescents do not deliberately trip over their own feet. When someone is asked to perform a specific motor task in a lab they pay close attention to what they are doing and use all their available senses – vision in particular – to perform the task properly. Whereas in everyday life the environment and task (such as climbing stairs or picking up a cup) are familiar and a lot of other things may be going on to pay attention to. A person's internal sense of their body and where it is in space (their body schema and proprioceptive feedback, (Stamenov, 2005)) allows them to perform tasks without looking at what they are doing or where they are going. It could be that the clumsiness that teenagers go through when they are growing rapidly only shows up when they are relying on sensory feedback from internal sources (not vision) (Quatman-Yates et al., 2012). Adolescent motor awkwardness may be related to adolescents' sense of their own bodies' dimensions and awareness of their limbs' movement in space. When the body grows rapidly it may take a while for the brain to become aware of how big the body has become because there is no sensory feedback which tells how big the body is. What we do have is the body schema.

1.2.7 Body schema

The body schema is an unconscious representation of the size and proportions of the body and how it functions (Berlucchi & Aglioti, 1997; Ivanenko, et al., 2011; Maravita & Iriki, 2004; Stamenov, 2005). Motor performance relies on body schema because it provides awareness of limb length and plays a role in posture. The first basic definition of body schema, proposed by Head & Holmes in 1911/1912 (as cited in Stamenov, 2005) was: "a combined standard against which all subsequent changes of posture are measured before these changes enter consciousness". Since then there have been various, similar, ways of defining it, particularly to differentiate it from the conscious awareness of our own body which falls instead under the definition of "body image" (Paillard, 1999; Rossetti, Rode, Farnè, & Rossetti, 2005). Body schema is more than proprioception which is internal sensory feedback that gives information to the brain about joint angles, movement and muscle tension. There is no internal sensory feedback that tells the brain what the size and proportions of the body are, the body schema is constructed based on sensory information that comes from experience interacting with the environment (Assaiante et al., 2014). This is why we can adapt to using tools and why amputees can learn to use mechanical limbs despite getting no internal sensory feedback directly from these external objects. The brain uses the body schema as a store of information about body size and proportions as well as where the various body parts are located in relation to each other and to the surrounding environment (Berlucchi & Aglioti, 1997; Ivanenko, et al., 2011; Maravita & Iriki, 2004; Stamenov, 2005).

The body schema is used by the motor control system as a reference frame for organizing and coordinating movement (Ivanenko, et al., 2011; Viel et al., 2009). Sensorimotor feedback contributes to the body schema through feedback coming from the visual, vestibular, tactile and proprioceptive systems about the configuration of the body and its orientation in space (Assaiante et al., 2014; Ivanenko, et al., 2011; Viel et al., 2009).

The body schema is both conservative and adaptive at different levels. The conservative body schema is demonstrated in phantom limbs, the sensation felt by an amputee in their phantom limb decades after limb amputation has occurred. This may have to do with a permanent representation in their brain of the lost body part (Berlucchi & Aglioti, 1997; Melzack, 1990). The body schema has been shown to be “prewired by genetics”: even if someone is born without a limb they still have a representation of that limb in their brain (Berlucchi & Aglioti, 1997) although it may not be complete (Melzack, 1990). After amputation the phantom limb matches anatomically with the size of the limb before amputation, at least at first. With time the phantom limb may fade away or shrink. However the neural representation of the limb may persist so that the feeling of a full-sized phantom limb returns with neural stimulation (Berlucchi & Aglioti, 1997; Melzack, 1990). Amputees who use a prosthetic limb report that their phantom limb matches the size and shape of the prosthetic (Melzack, 1990). This suggests that we learn the size of our body based on sensory feedback from interacting with our environment and the brain constructs (or adapts) the body schema based on these experiences. There is no sensorimotor feedback that gives us an innate sense of our own body’s dimensions, but rather our brains construct (and/or we are born with) a mental representation of our body’s dimensions.

The body schema is adaptive when using tools (Carlson, Alvarez, Wu, & Verstraten, 2010; Maravita & Iriki, 2004; Berlucchi & Aglioti, 1997), perhaps more so than to changes in our own limb lengths. It may also be more adaptive where the hands (vs legs and feet) are concerned because we are more used to using tools with our hands (Ivanenko, et al., 2011). Tools can become integrated into body schema, though how easily and quickly is still under debate (Carlson et al., 2010; Maravita & Iriki, 2004). An object must be physically in contact with a person in order to be included in the brain’s representation of the body in some form (Carlson et al., 2010) but in order to be part of the body schema (and available in the brain for action planning) it may be necessary to have experience actively using the tool (Maravita & Iriki, 2004). When a person picks up a new tool they do not have inherent knowledge of all its’ physical properties, they cannot wield the tool with precision and accuracy without looking at the tool and how it is interacting with the environment until they have experience using it. The same may be true of our limbs as we grow.

1.2.8 Body schema and growth

There is a difference however between adapting the body schema to a tool and to increased body size. Growth challenges the brain differently than holding a tool because when a person grows they already have a body schema based on the previous size of their body and expect to be able to rely on that body schema in their interactions with the environment. Whereas when wielding a new tool we expect to have to adapt to the tool and spend time focusing on learning how to use it, like learning to ride a bicycle. As a person grows their brain has to constantly adjust their body schema to match the changing length of their limbs, otherwise it would seem that the environment is gradually shrinking in relation to their body size. These adjustments to the body schema are made extra complicated by the fact that growth does not happen in all parts of the body equally at the same time and so body proportions change during growth (see section 1.2.4 Adolescent growth, figure 1.3).

By adulthood the framework (bones) of our body have reached a set length and do not change again, except in unusual instances such as amputations, until old age (Malina et al., 2004). During growth

children and adolescents have to continually relearn what size their body is. This might not create a noticeable problem before the adolescent growth spurt because the changes are gradual. During the rapid growth of adolescence however, the changes in limb length and body proportions may create a large enough mismatch between the brain's representation of the size and proportions of the body and the reality to cause clumsiness.

1.2.9 Proprioception

Proprioception is an important contributor to the body schema, Assaiante et al. (2014) state that "Proprioception is likely the most important modality to body schema building, given that it provides direct information on the position and the dynamics of body segments." Proprioceptive feedback is necessary for performing actions without consciously focusing on, or being able to see, where the limbs are in relation to each other and the environment. Proprioceptive feedback tells the brain how the various segments of the body are moving in space based on signals from muscle, joint and cutaneous receptors. There are three submodalities of proprioception: joint position sense, kinesthesia, and sense of tension (Riemann, Myers, & Lephart, 2002). Joint position sense is the awareness of joint position and ability to reproduce joint angles from active or passive positioning of a body segment. Kinesthesia is the awareness of motion about a joint. Sense of tension is the awareness of force applied to move a body segment about a joint. (Riemann et al., 2002; Lattanzio & Petrella, 1998; Smith et al., 2013) All together the three submodalities of proprioception tell the brain when and how a limb is moving and what angles the joints are at throughout the movement.

1.2.9.1 Measuring proprioception and body awareness

Endpoint position matching has been used to measure proprioception at a single joint and across multiple joints (Goble, 2010; Jola et al., 2011; Smith et al., 2013; Stillman & McMeeken, 2001). Endpoint position matching is commonly used to test proprioception at a single joint such as the knee (Smith et al., 2013). This is carried out by either actively (participant moves their own leg) or passively (tester moves participants leg) positioning the limb so that the joint is at a particular angle and then having the participant either match that angle with the opposite limb or attempt to reproduce the angle with the same limb. Endpoint position matching has also been used to test integration of proprioceptive feedback and body schema across multiple joints in order to test awareness of where a limb is in space rather than just the angle of a particular joint (Jola et al., 2011). Jola et al. (2011) used endpoint position matching across multiple joints in order to compare dancers' and non-dancers' body awareness; they had participants' match the position of one hand with the other, both with vision and without. To test awareness of the position of a foot in relation to the body and also to external objects it is necessary to measure across multiple joints. Proprioceptive feedback provides information about specific joint angles and muscle tension but not limb length (Ivanenko, et al., 2011; Longo & Haggard, 2010). Proprioceptive feedback from individual joints is combined with other available sensory feedback and integrated into the body schema to inform the brain where the foot is in space. Proprioceptive feedback combined with knowledge of body proportions is intuitively important for basic physical literacy, sport specific skill development and for performing in a dynamic environment (Balyi et al., 2005).

1.2.10 Sport specific skills

According to the Canadian Model of Long-Term Athlete Development adolescence, defined loosely as the period around PHV (Balyi et al., 2005), is a time to develop sport specific skills (Training to Train stage). Skill is defined by Knapp (1977) as “the learned ability to bring about pre-determined results with maximum certainty often with the minimum outlay of time or energy or both” (as cited in Ali, 2011). Sport specific skill, in addition to physiological capacity, is essential in order to be competitive at a high level (Vanderford, Meyers, Skelly, Stewart, & Hamilton, 2004). Not only is skill and physical capacity important in a game such as soccer but also the ability to select and perform actions with appropriate force and direction (Ali, 2011). During a soccer game players need to be able to pay attention to the dynamics of the game (watch for the ball and other players) (Williams, 2000) and so they have to depend on their body schema and proprioceptive feedback to know where their feet are while their focus is elsewhere. A growing teenager’s feet may be further from their centre of gravity and on the end of longer levers (legs) than their brain thinks they are and this could necessitate adjustments in the performance of skills which may have been well-rehearsed and automatic.

1.2.11 Summary

As children become adolescents they start to grow rapidly and sometimes appear to lose sense of their body size and are labelled as being clumsy. Adolescent’s sensorimotor systems may still be developing and they fall somewhere between children and adults in their reliance on vision versus proprioception during performance of motor tasks. When a person can’t see their foot they must rely on accurate sensorimotor feedback combined with inherent knowledge of their body (their body schema) to appropriately place the foot in relation to objects in the environment. There may be a period around PHV when the body schema lags behind the body’s growth and this affects awareness of where the limbs are in space. For a growing adolescent this may result in them appearing clumsy as they attempt to perform familiar motor tasks as their body changes size. This adolescent awkwardness may manifest in interactions with the environment rather than in performance of simple coordination, strength or speed tasks. That teenagers grow so fast their brains can’t keep up is the intuitive explanation given for teenage clumsiness but it has not been proven.

1.2.12 Purpose and hypotheses

The purposes of this study therefore are:

- 1) Explore the phenomenon of adolescent awkwardness by examining if female adolescents’ awareness of their body size and movement is influenced by maturity status (as represented by months from predicted APHV) and
- 2) Test if adolescent awkwardness can be detected in sport specific skills which are independent of strength.

It is hypothesized that 1) Around PHV adolescents have decreased awareness of their body size and movement as measured by an endpoint matching task with the foot. 2) Around PHV there is a decrease in sport specific skills which are independent of strength.

The results will help to show if an endpoint matching task or soccer skill tests can detect changes in body awareness around PHV which may be connected to adolescent awkwardness. If a period of adolescent awkwardness exists and can be detected, this might help coaches, athletes and parents understand why some youth may appear to lose skill or not gain skill as quickly when they are growing rapidly.

CHAPTER 2

2.0 Methods:

2.1 Study Design:

This was a cross-sectional study, two data collection periods took place each with a different group of participants. The first was between June and July 2014, the second was in January 2015. The participants in this study were a convenience sample of 36 female adolescent soccer players who were either part of a U12 girls' premier division local soccer team or training with a Saskatchewan Soccer Association High Performance Development Centre (HPDC) group. The eligible age range was 10-14 years encompassing the 4 years around the average age of PHV (age 12 years in girls). The players who were part of the local soccer team were aged 10-11, this group had been in organized soccer for an average of 7 ± 2 years and were training an average of 6 ± 2 hours/week in soccer (10 ± 3 hours/week including training in other sports). The players who were training with the HPDC group had been in soccer for an average of 8 ± 2 years and were training an average of 8 ± 2 hours/week in soccer (10 ± 2 hours/week including training in other sports). The two groups were combined for the analysis and classified into three maturity groups based on biological maturity. The three groups were Pre-PHV, PHV and Post-PHV, participants were classified based on how many months they were from their predicted age of peak height velocity (APHV). The Pre-PHV were those participants who were greater than 6 months before their predicted APHV, the PHV group were those participants who were within 6 months of their predicted APHV, the post-PHV group were those participants who were greater than 6 months past their predicted APHV. There was no separate control group.

In addition to being a female soccer player age 10-14 years participants had no history of a motor coordination disorder. This selection was done through inviting participants who were participating in soccer camps which targeted high performance athletes and through self-selection based on the description of "Who can participate in the study" on the consent form (Appendices [B](#) and [C](#)). Data collection took place in a church or school gym or soccer centre in Saskatoon, either during or after practice or on a separate occasion entirely.

Ethics approval was obtained through the University of Saskatchewan Biomedical Research Ethics Board, Bio #: 13-279 (Appendix [A](#)). Parents and coaches were informed about the study before potential participants were approached. Consent and assent forms were given to athletes and their parents prior to data collection. Youth who wished to participate signed assent forms and their parents signed consent forms before any data was collected. All procedures were explained carefully to participants and their parents. Individual participants' results were kept confidential; Individual participants' scores were not given to their coaches. Participants were assigned ID codes for analysis of their results so they cannot be identified by name and connected to their individual results.

2.2 Measurement procedures

2.2.1 Soccer & sport background questionnaire

Participants were asked to fill out a simple questionnaire created for this study (Appendix E) to determine years of participation in sport, soccer participation specifically, soccer training history, and foot dominance.

2.2.2 Biological Maturity

Biological maturity was predicted using a gender-specific multiple-regression equation that relies on age, body mass, leg length and sitting height to predict APHV. The equation developed by Mirwald et al. (2002) provides a relatively accurate (± 6 months) way of estimating biological maturity with cross-sectional data. The equation for girls is: $\text{Maturity Offset} = 9.376 + 0.0001882 \cdot \text{Leg Length} + \text{Sitting Height interaction} + 0.0022 \cdot \text{Age} + \text{Leg Length interaction} + 0.005841 \cdot \text{Age} + \text{Sitting Height interaction} - 0.002658 \cdot \text{Age} + \text{Weight interaction} + 0.07693 \cdot \text{Weight by Height ratio}$. The equation is the basis of an online growth utility program for calculating APHV that is available at http://taurus.usask.ca/growthutility/phv_ui.cfm?type=1.

Body weight and height measurements were performed by a research assistant familiar with the Canadian Society for Exercise Physiology (CSEP)'s protocol for these measurements. This protocol is outlined in the CSEP Physical Activity Training for Health (CSEP-PATH) manual (2013). Height, sitting height and body weight were all measured twice and recorded to the nearest .1cm or .1kg. The mean of the two measurements was used in analysis. If the two measurements differed by more than 0.1 kg or 0.5 cm a third measurement was taken and the mean of the two closest measurements used. Weight was measured using a Seca brand (seca: medical measurement systems and scales) flat scale, standing height and sitting height were measured using a Seca brand portable stadiometer; leg length was calculated by subtracting sitting height from standing height.

2.2.3 Soccer skill

Two measures of soccer specific skill were used: a ball juggling task and the Johnson wall volley (Ali, 2011; Baumgartner, Jackson, Mahar, & Rowe, 2003; Collins & Hodges, 2001). The juggling task measures soccer specific coordination and ball control and the wall volley measures kicking accuracy and trapping ability (Ali, 2011; Baumgartner, Jackson, Mahar, & Rowe, 2003; Collins & Hodges, 2001). These are two tests of soccer skill which do not rely on strength and so are less likely to be affected by the increases in strength that occur with maturation. Participants were given time to warm-up and do a practice trial of each of the two tasks if they wished.

Test 1, the juggling task, involved keeping the ball aloft by tapping it with the foot or knee for up to 30s, the outcome variable was the number of taps. The participant had to remain within a 9x9 foot square outlined with tape on the floor. If the ball was dropped or the participant went outside of the marked area the trial was ended and the number of taps to that point was recorded. The researchers timed the trials and counted the number of taps, the participant's best trial was used for analysis. The juggling task has previously been found to have a validity coefficient of 0.74 (Baumgartner et al., 2003) and a reliability coefficient of 0.77 (Figueiredo, Coelho e Silva, & Malina, 2011).

Test 2, the wall volley test, involved rebounding a ball as many times as possible in 30 seconds from behind a restraining line 15 feet in front of a target on a wall, the outcome variable was the number of rebounds (Ali, 2011). The ball could be kicked immediately after it rebounded or trapped first. For the rebound to count the non-kicking foot had to remain behind the restraining line and the ball had to hit within an 8x24 foot (regulation soccer goal size) target outlined with tape on the wall (Baumgartner et al., 2003). The researchers timed the trials and counted the number of rebounds, the participant's best trial was used for analysis. The wall volley test previously had a validity coefficient of 0.85 and a reliability coefficient of 0.92 (Ali, 2011).

2.2.4 Endpoint matching task

An endpoint position matching task was used to measure awareness of foot position which reflects use of proprioceptive feedback integrated with body schema. This task involved participants lining their foot up with an endpoint position marked on the wall and then attempting to match that position with their eyes closed or open. Three target endpoints were used, all in the sagittal plane from the participants' viewpoint but varying along an upward slope in height and distance from the starting position of the participant's foot. A removable + was used to mark the endpoint positions. The + was placed on 3 different locations on a 5x5cm grid on stiff poster-board, the 3 endpoint locations were at 3x10 (A), 4x8 (B) and 5x6 (C) for right footed participants and 3x6 (A), 4x8 (B) and 5x10 (C) for left footed participants (figure 2.1). The distance between the participants starting position and the endpoint locations were: A = 20cm horizontal and 18 cm vertical, B = 30 cm horizontal and 23 cm vertical, C = 40cm horizontal and 28 cm vertical.

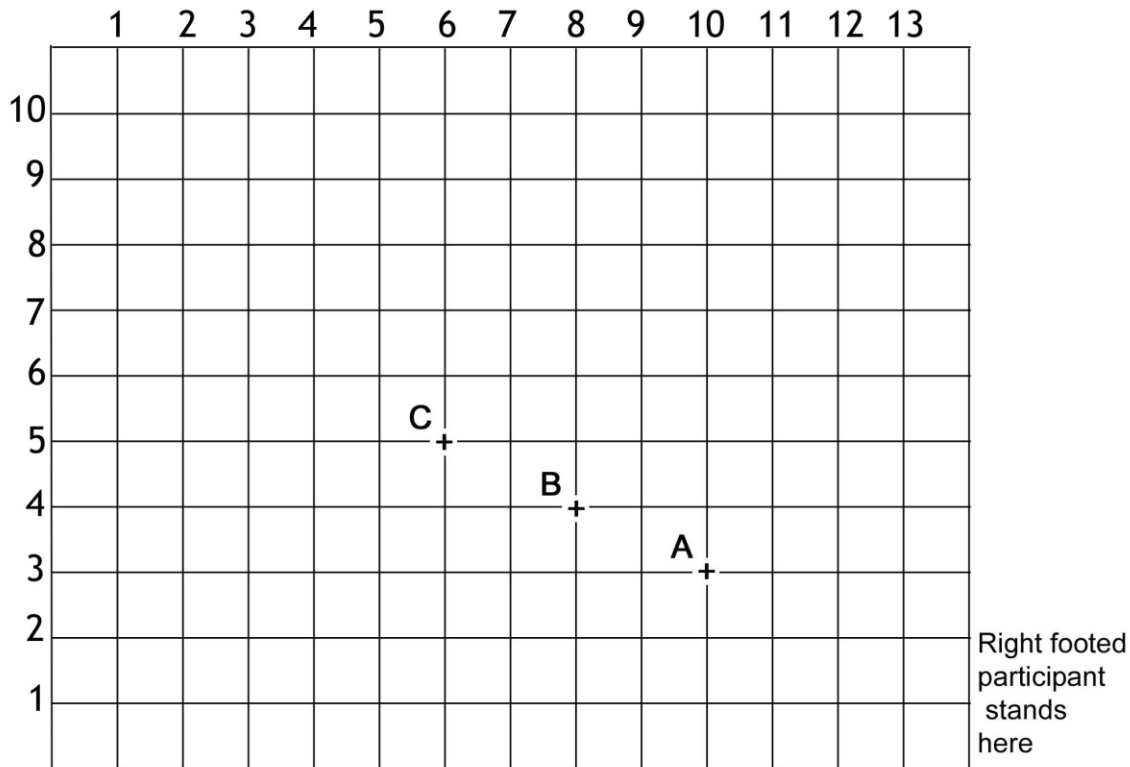


Figure 2.1 Example of grid and endpoint positions A, B, and C used for endpoint matching task for right footed participants.

Participants stood parallel to a wall with a hand on the wall for balance, their toes at the edge of the grid on the wall and their dominant foot closest to the wall. A round black marker was taped to their shoe over the big toe of their dominant foot. The participant's foot and leg were free in space, not touching the wall or any other object. The participants held their foot in position for about 5 seconds while a photograph was taken before returning it to the starting position. 3 repetitions at each of the 3 locations were performed for each leg both with and without the participant's eyes closed (18 trials). The order of the trials was randomized ahead of time using a random number generator available online at <http://www.random.org/lists/>. The + was removed from the wall for the trial with vision so that participants had visual feedback of where their foot was in space but not where it was supposed to be. This was done so that the eyes open (visual) and eyes closed (proprioceptive) conditions differed only by whether the participant could see where their own foot was in space or not.

For each trial a reference endpoint and a matching endpoint photograph were taken (Figure 2.2 b and c). First the + was placed at one of the endpoint locations (Figure 2.2a) and then the participants were asked to position their foot so that the marker on their big toe approximately lined up with the + (figure 2.2b); this was the reference endpoint position. The + was then removed from the wall and the participant attempted to return their foot to the same position (figure 2.2c); this was the trial endpoint position. For the reference endpoint part of each trial (figure 2.2b) the participant could always see the

+ (where they were aiming to place their foot, the endpoint location). For the endpoint matching part of the trial (figure 2.2c) the participant could never see the + because it was either removed from the wall or they had their eyes closed.



Figure 2.2 Photos from a left footed participant performing the endpoint matching task. a) Grid with + at position C, b) Reference endpoint position, c) Trial endpoint position.

A Nikon Coolpix P90 12.1MP digital camera was used to take the photographs. Before any trials were done the camera was leveled on a low tripod around 55cm from the wall. A calibration photo to be used in analysis was taken before participants performed the task. This was done by taking a photograph of the grid used for placing the markers while it was held upright and approximately in line with the plane in which the marker on a participant's toe would be.

Photographs from the trials were analyzed using ImageJ (Rasband) to determine the difference (mm) between the reference endpoint position and the trial endpoint positions. This difference is the endpoint match error (EME) (Figure 2.4). The photographs were put into random order for analysis by using the Bulk Rename Utility program (Bulk Rename Utility 32-bit (Unicode), 2010) to randomly sort the images and then rename them with a prefix 1, 2, 3... The x and y location of the marker on the participant's toe was found by using the oval selections tool in ImageJ to select the marker and then the "Centroid" measurement to get the X and Y coordinates of the center of the selection (figure 2.3). These coordinates were then entered in Excel and the reference and trial endpoint position photographs matched up.

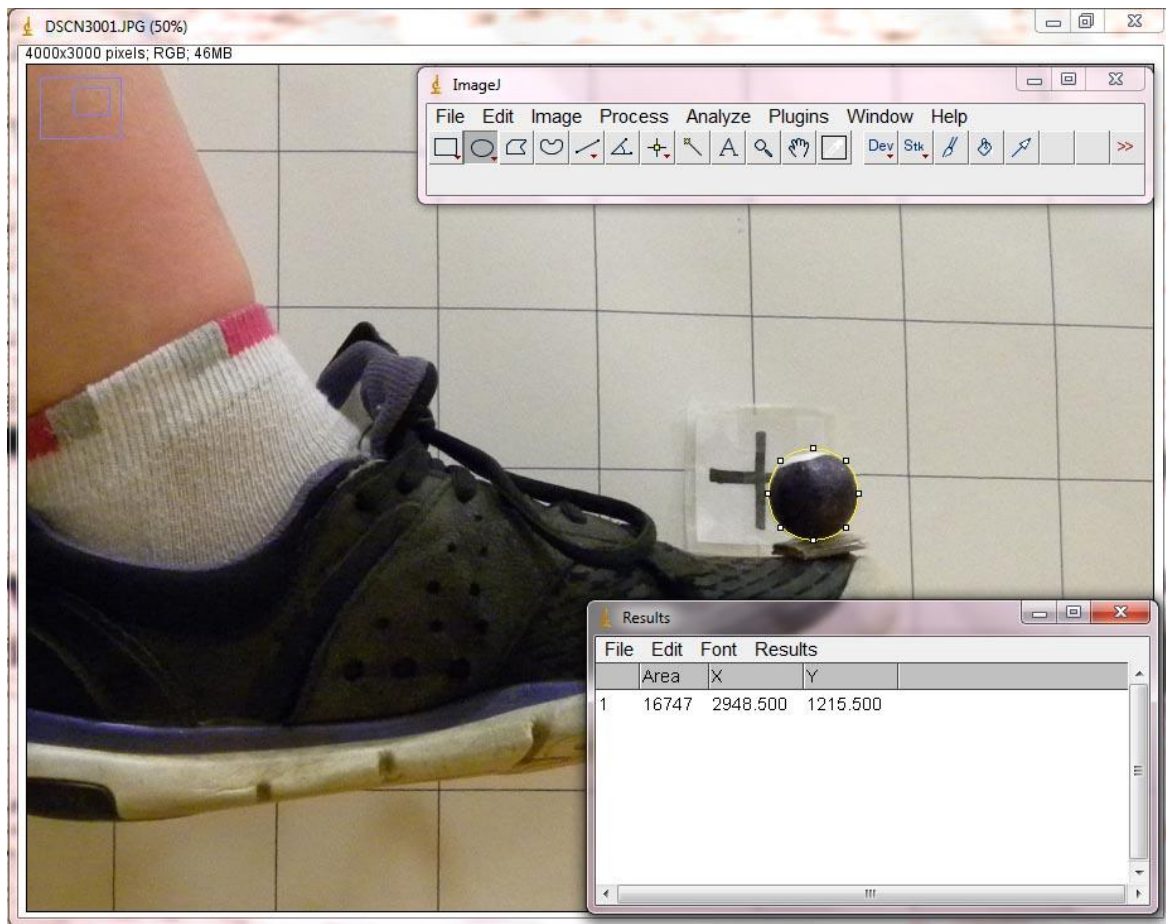


Figure 2.3 Finding X, Y coordinates of marker on participant's toe using ImageJ.

The difference between the X and Y location of the marker on the participant's toe in the reference and endpoint images was calculated using Pythagoras' theorem ($d = \sqrt{[(X1-X2)^2 + (Y1-Y2)^2]}$, where d = the absolute distance between point 1 (reference) and point 2 (endpoint). The distance between point 1 (reference image) and point 2 (trial image) was then converted to mm using a conversion factor determined from the calibration photo. A conversion factor was determined for each of the 3 endpoint matching locations based on the calibration photo for each set of trials. The conversion factors were calculated by dividing the measured distance in ImageJ by the real distance of two diagonal lines criss-crossing the endpoint matching location. Measurement accuracy was determined as ± 0.2 mm based on the average difference of repeat measurements of x and y location of the marker on 89 photos multiplied by the highest conversion factor from image pixels to distance in mm on the calibration photo.

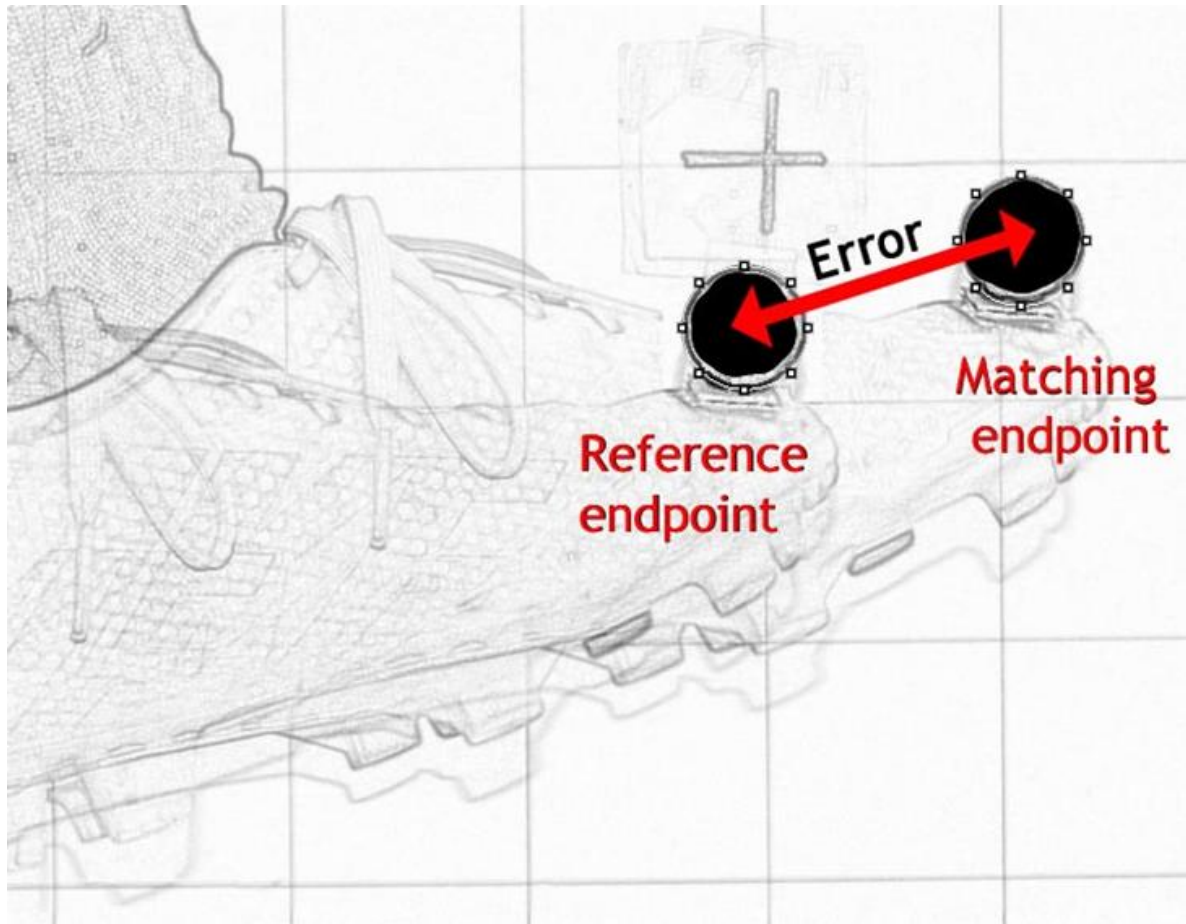


Figure 2.4 Endpoint matching error (EME) determined from difference between the reference and matching endpoints.

2.3 Statistical analysis

Descriptive statistics were presented as means and standard deviations. Group differences were compared using ANOVA. Pearson's correlation coefficients were used to test for relationships between possible confounders and outcome variables. No significant confounders were found.

Performance on the soccer skills tests was analyzed using 2 separate ANOVAs, one for the Wall Volley test and one for the ball juggling task. Number of rebounds on the wall volley test and number of taps on the ball juggling task were the dependent variables, while maturity group was the independent variable. Performance on the endpoint matching task was analyzed using ANOVA with EME as the dependent variable maturity group as the independent variable. Statistical analysis was conducted using SPSS v22.0 software (IBM corporation) with alpha set to 0.05.

CHAPTER 3

3.0 Results

3.1 Descriptive statistics

Of the thirty six soccer players recruited for this study twenty eight performed both the soccer tasks and endpoint matching task while 8 participants were unavailable for the endpoint matching task and performed only the soccer tasks. The participants recruited were all female soccer players between the ages of 10 and 14 years (not yet reached their 15th birthday) (Table 3.1). The Post-PHV group was significantly taller and older than the other two groups ($p < 0.05$). There was a significant difference between all the groups in predicted months from PHV ($p < 0.05$). Participants were asked to pick their dominant foot based on which foot they prefer to use for kicking a soccer ball; 24 declared themselves right footed, 2 dual footed, 3 left footed and 7 did not declare but used their right foot for the endpoint matching task.

Table 3.1 Mean growth measures and amount of soccer training grouped by biological maturity.

Maturity group	Pre-PHV	PHV (± 6 months)	Post-PHV	All
Number of participants	6	5	25	36
Chronological age <i>in years</i>	11.7 \pm 0.8	12.1 \pm 0.9	*14.0 \pm 0.8	13.4 \pm 1.3
Height <i>in cm</i>	146.4 \pm 7.2	153.1 \pm 6.3	*161.9 \pm 3.7	158.0 \pm 7.7
Sitting height <i>in cm</i>	69.5 \pm 11.8	74.7 \pm 12.4	80.7 \pm 8.2	78.0 \pm 10.1
Weight <i>in Kg</i>	41.0 \pm 19.6	51.2 \pm 20.4	58.1 \pm 14.5	54.3 \pm 17.0
Predicted age of PHV <i>in years</i>	12.5 \pm 0.7	12.2 \pm 0.9	12.5 \pm 0.5	12.5 \pm 0.6
Predicted months from PHV <i>in months</i>	*-10.4 \pm 3.4	*-1.2 \pm 3.5	*18.4 \pm 6.2	10.9 \pm 13.0
**Years in organized soccer (range)	7 \pm 1 (5-8)	6 \pm 2 (3-9)	8 \pm 2 (2.5-12)	7 \pm 2
**Hours of soccer training per week (range)	6 \pm 2 (4.5-9.5)	7 \pm 2 (5-9)	8 \pm 2 (4-10)	7 \pm 2
**Total hours of training per week, not just soccer (range)	9 \pm 2 (7-11.5)	10 \pm 4 (6-16)	10 \pm 2 (6.5-13)	10 \pm 2

**7 participants in the post PHV group did not fill out this portion of the questionnaire

*Represents statistically significant difference $p < 0.05$

3.2 Soccer skills

The PHV group performed worse on the Johnson wall volley task than those in the Pre-PHV (marginally) and Post-PHV groups (significantly ($p < 0.05$)). The post-PHV group performed significantly ($p < 0.05$) better than the Pre-PHV and PHV groups on the ball juggling task with an average of 6 to 7 times more taps. These results are illustrated in figures 3.1 and 3.2 below.

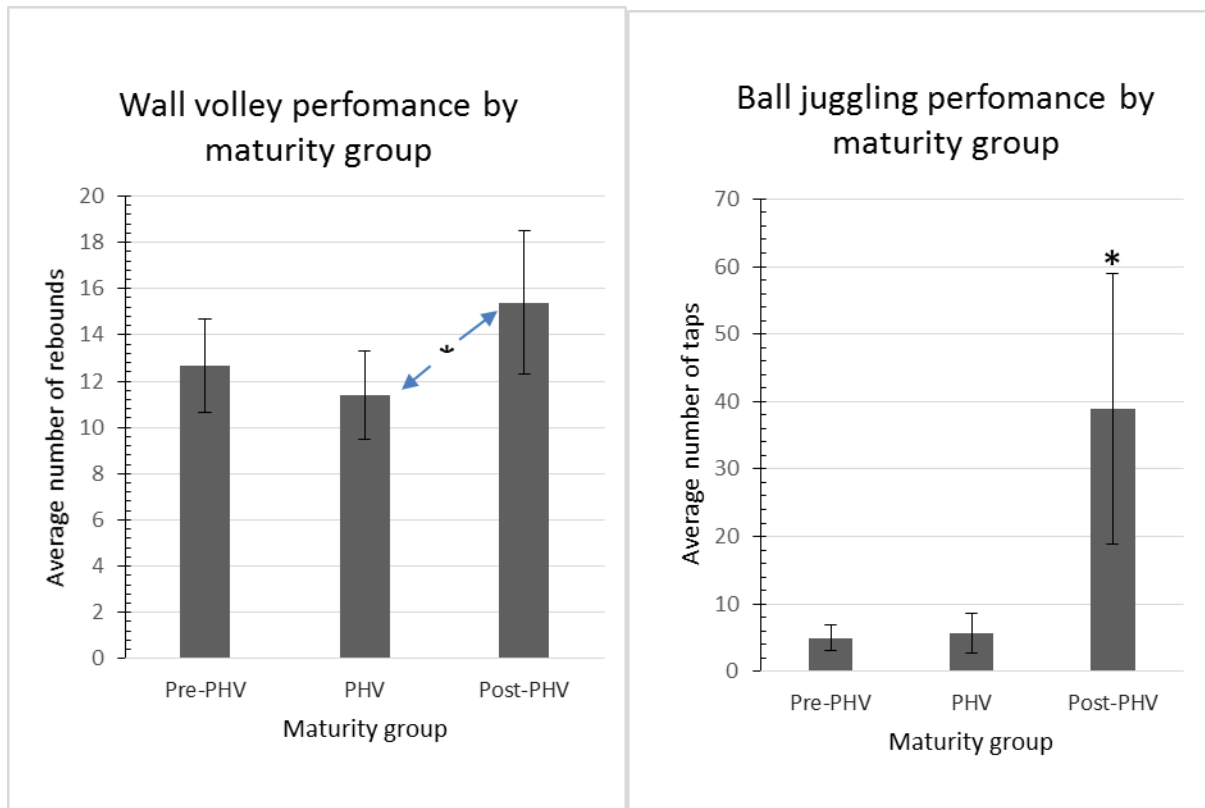


Figure 3.1 Comparison of maturity groups by wall volley performance.

Error bars represent standard deviation.

*Represents significant difference, $p < 0.05$.

Figure 3.2 Comparison of maturity groups by ball juggling performance

Error bars represent standard deviation.

*Represents significant difference, $p < 0.05$

3.3 Endpoint matching task

Endpoint matching error (EME) is the difference between the location of the participant's foot at the reference and trial endpoint positions. Measurement accuracy was determined as ± 0.2 mm. Average EME with eyes open was 20.9 mm while average EME with eyes closed was 25.3 mm with a statistically significant difference of 4.4 mm, $p < 0.05$ (Table 3.2).

Table 3.2 Mean EME (distance between reference and trial foot locations) with eyes open, eyes closed, and the difference between eyes open and eyes closed for each of the 3 maturity groups.

Maturity group	Pre-PHV	PHV (± 6 months)	Post-PHV	All
Eyes open EME (mm)	23.6 \pm 14.4	23.4 \pm 14.0	19.3 \pm 12.7	20.9 \pm 13.4
Eyes closed EME(mm)	27.5 \pm 15.7	32.8 \pm 17.6	22.2 \pm 13.9	25.3 \pm 15.6
Difference between eyes closed and eyes open EME (mm)	3.9	9.4	2.3	4.4

* $p < 0.05$

There was no significant difference between the maturity groups when the task was performed with eyes open (Figure 3.3). When the task was performed with eyes closed there was a statistically significant difference ($p < 0.05$) of 10.6 mm between the EME of the Post-PHV group and the PHV group, with the PHV group performing worse than the Post-PHV group. The difference between the EME of the Pre-PHV and PHV groups was not statistically significant at 5.3 mm ($p < 0.05$). This is shown in figure 3.3 below.

Though it was not statistically significant all around, the Post-PHV group was more accurate than the other two groups both with eyes open and eyes closed (Figure 3.3). In fact the post-PHV group performed better with eyes closed than the Pre-PHV group did with eyes open.

It is particularly interesting to compare the maturity groups based on the difference between eyes open EME and eyes closed EME because this accounts for any differences between groups with eyes open. The difference between the Post-PHV group and the Pre-PHV group shrinks from around 5 mm to around 2mm when eyes open EME is subtracted from eyes closed EME (figure 3.4). When the groups are compared by the difference between eyes closed and open EME the PHV group performed the worst. The difference between eyes closed and open EME for the PHV group was 9.4mm while it was 3.9mm and 2.3mm for the Pre-PHV and Post-PHV groups respectively. Doing this reduced the n for statistics to be equal to the number of participants in each group. The calculation was as follows:

Example calculation of difference between eyes open and eyes closed endpoint matching error for one participant

$$E_{c-o} = [((A1c + A2c + A3c) + (B1c + B2c + B3c) + (C1c + C2c + C3c))/3] - [((A1o + A2o + A3o) + (B1o + B2o + B3o) + (C1o + C2o + C3o))/3]$$

Where:

E_{c-o} = difference between average eyes closed endpoint matching error and average eyes open endpoint matching error

A1c = Distance between reference and matching endpoint xy position calculated from the 2 images for endpoint location A (A) trial 1 (1) with eyes closed (c)

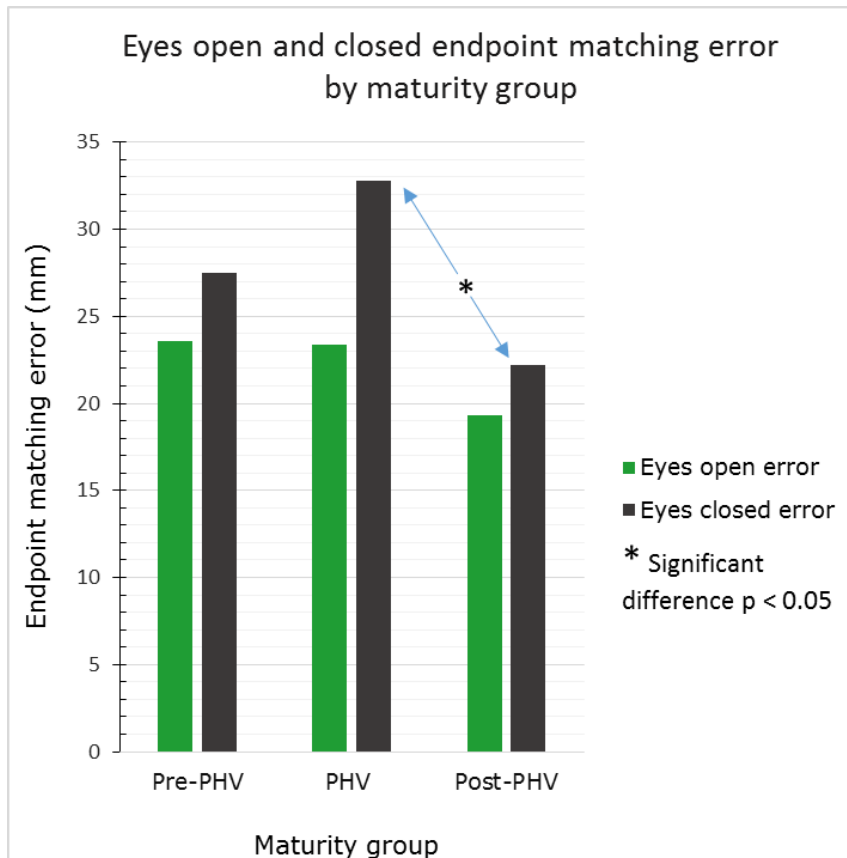


Figure 3.3 Comparison of maturity groups by eyes open and closed EME.

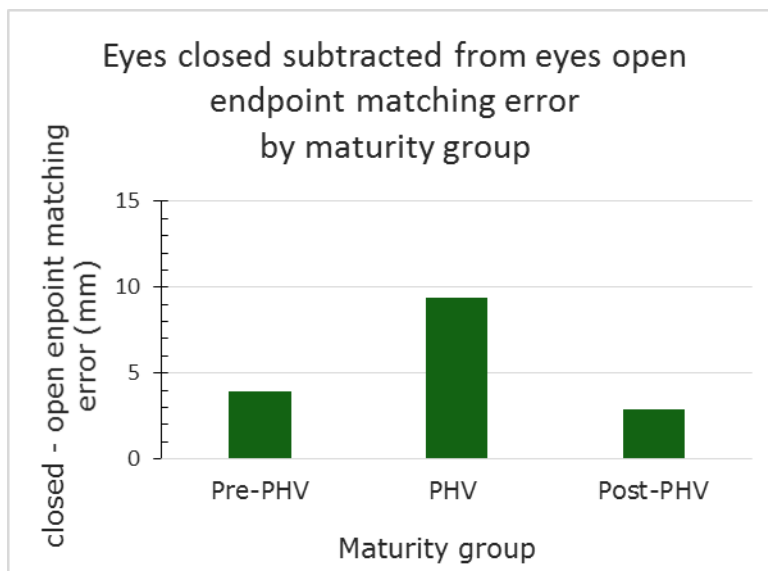


Figure 3.4 Comparison of maturity groups by difference between eyes closed and eyes open EME.

Insufficient sample size to determine significant differences.

CHAPTER 4

4.0 Discussion

The results of this research suggest that a phase of adolescent awkwardness may exist, although the small numbers in pre and PHV groups are problematic as is the older age of the post PHV group. It is a common assumption that rapid growth during adolescence is associated with a clumsy teenage phase (BBC, 2014; Reynolds, 2011); however, previous research has been unable to prove that this phase actually exists. More often than not previous studies have shown that there is no plateau or drop in physical performance around the time of rapid growth during adolescence (Butterfield et al., 2004; Davies & Rose, 2000; Malina et al., 2005; Quatman-Yates et al., 2012). Youth athletes, and their parents and coaches, may be particularly concerned if they become a “clumsy teenager” because of the impact it could have on their sports performance and selection for teams. The focus of this study was on body awareness and coordination during adolescence rather than on physical performance that relies on strength. Body awareness is challenged during growth as the body schema has to catch up to the changes in size and shape of the body.

The purposes of this study were to: 1) Explore the phenomenon of adolescent awkwardness by examining if female adolescents’ awareness of their body size and movement is influenced by maturity status (as represented by months from predicted APHV) and; 2) Test if adolescent awkwardness can be detected in sport specific skills which are independent of strength.

The results of this study suggested that adolescents may not have as much awareness of their body size, as tested with the endpoint matching task, during the year around PHV as before or particularly after PHV. The PHV group performed worst on the endpoint matching task, though this result was only statistically significant when the PHV group was compared to the post-PHV group. The results of the soccer skills tests suggested that the rapid growth around PHV may also affect adolescents’ performance of sport specific skills. There was a small decrease (wall volley) and no difference (ball juggling) in performance by the PHV group compared to the pre-PHV group on the soccer skills tasks while the post-PHV group performed a lot better on both soccer tasks than either of the other maturity groups. The present study provides some evidence of the existence of “teenage clumsiness” as well as an explanation for why this phenomenon occurs and how it can be detected.

There are a lot of body changes occurring during adolescence. The physical changes include a growth spurt in height, increases in muscle size and strength and changes in body composition. Girls’ reach an average peak height growth rate of 9cm/year (Tanner J. M., 1990), this growth does not occur uniformly throughout the body but rather in stages over a few months. The hands and feet are the first to increase in size, serving as a good indicator of growth to come, then the legs grow half a year or more before the trunk (Tanner J. M., 1990). This means that throughout the year around PHV not only is the body rapidly increasing in size but the proportions of the body also vary. The brain must adapt the body schema to these changes to accurately coordinate the limbs with the surrounding environment, particularly when relying solely on internal body awareness and not on vision. Performing the endpoint

matching task with eye closed required participants to rely on their body schema, that the PHV group performed worst shows that they did not have as good internal awareness of their body as their peers in the other maturity groups.

In a 2013 article, Assaiante et al. discuss “body schema building during childhood and adolescence” through a neurosensory perspective from various developmental studies. They did not examine any connection to adolescent awkwardness directly but emphasize the findings that body schema matures slowly throughout childhood and growth “making updating of internal models of action more difficult in children than in adults.” (Assaiante et al., 2014). This was particularly evident in adolescents’ postural control strategies, as also discussed by Quatman-yates et al (2012). Children rely more on vision for stabilizing their body in space where adults rely more on somatosensory mechanisms (proprioception and vestibular organs). Adolescents fall somewhere in between and may actually regress in use of proprioception for postural control as they grow rapidly (Quatman-Yates et al., 2012; Assaiante et al., 2014). This temporary regression in use of proprioceptive feedback causes changes in the way adolescents stabilize their body and so experience a “transient loss of reference point, which [is] probably linked to a disturbance of body schema.” (Assaiante et al., 2014). Though how long it takes for the body schema to be updated to changes due to growth has yet to be elucidated and may be a direction for future research.

4.1 Endpoint matching tasks

In the present study those participants who were in the PHV group performed worse on the endpoint matching task than the participants in both the pre- and post- PHV groups. Although this finding was only statistically significant ($p < 0.05$) for the difference between the PHV and Post-PHV groups. These results fit with the hypothesis that there is a temporary decrease in awareness of body size and movement around PHV. It was hypothesized that this would show up in tasks where it is necessary to rely on body schema and proprioception instead of vision and where performance is independent of strength or body size. The endpoint matching task used in this study was designed to meet the specifications of this hypothesis and so showed that teenage clumsiness exists and is indeed related to a temporary decrease in internal body awareness. This is the first study to examine teenage clumsiness also known as adolescent awkwardness by using an endpoint matching task, previous studies of adolescent awkwardness have looked at physical performance (Butterfield et al., 2004; Davies & Rose, 2000; Quatman-Yates et al., 2012; Visser et al., 1998).

As expected, performance on average for all participants regardless of maturity group was worse with eyes closed than with eyes open. Performance of the Pre-PHV and PHV groups was almost the same with eyes open, while the Post-PHV group performed better than the other two groups with eyes open. This makes it interesting to look at the difference between groups when EME with eyes open is subtracted from EME with eyes closed. This accounts for how much EME vision accounts for, the greater the difference between eyes open and eyes closed EME the more reliance there was on vision. This comparison particularly highlights that the PHV group was least accurate at the endpoint matching task. The differences in EME between the Pre-PHV and Post-PHV group shrink when looking at the eyes open EME subtracted from eyes closed EME rather than the difference between groups with eyes closed

or open separately. This finding emphasizes that body awareness is better before and after PHV than during the year around PHV.

4.2 Soccer tasks

The results of the soccer tasks show that there is either no change or a small decrease in performance with the adolescent growth spurt. Following the adolescent growth spurt, performance of soccer skills improves dramatically, though this result may partly be a result of the specific soccer skills training done and the skills tested.

The majority of growth and development studies examining physical skill during the adolescent period have focused on strength and speed based tasks (Butterfield et al., 2004; Isaacs et al., 2003; Philippaerts, et al., 2006). These studies have found continuous improvement in performance throughout adolescence in general and sometimes a decrease or plateau in performance on one specific task or amongst some children. Butterfield et al. (2004) found continuous improvement in running and vertical jump performance over a 9 month period in adolescents aged 11-13; some children decreased in performance from September to May. The vertical jump standards for children aged 7-11 compiled by Isaacs et al., (2003) shows that jump performance improves from ages 7-11 in girls and boys but that boys age 10 perform better than boys age 11, they don't include jump standards beyond age 11. Philippaerts et al. (2006) found the greatest improvements in physical performance occurred around PHV, only the results for the 30m dash stood out apart from this trend: "Performance of the soccer players in the 30m dash showed an inverse relationship with height growth in the year before peak height velocity, but estimated velocities became and remained positive (improving performance) at peak height velocity." The explanation given for these results was "adolescent awkwardness". Further study would be needed to know whether that explanation truly explains the results of performance on the 30m dash. Performance on a 30m dash would theoretically be affected by increases in strength with growth.

The Johnson Wall Volley and the Ball juggling soccer tasks were chosen for this study because performance of these tasks does not rely on strength which increases with growth and maturation during adolescence. Davies & Rose (2000) used the same logic in choosing the tasks for their study comparing motor skills in prepubertal, pubertal and postpubertal adolescents: their study was "unique in that the motor tasks, such as knocking over glasses and running into objects, were chosen for possible sensitivity to this hypothetical awkwardness." However they found no evidence of an awkward stage in adolescent development. The present study differed from the one by Davies & Rose and all others in that it used an endpoint matching task as well as motor tasks. The endpoint matching task was designed to test changes in body awareness during adolescence by comparing participants' accuracy of foot placement when relying on body schema and proprioception. The results of the present study, though not conclusive, suggest that there is a period around PHV during which performance may be slightly impaired or at least plateaus and that after PHV performance improves.

Similar to the present study Malina et al., (2005) used the ball juggling task (along with 5 other measures of soccer skill) in their study of high performance soccer players aged 13-15. Differences between soccer skill performance by sexual maturity were compared using ANCOVA with age, body height and

body weight as covariates. There was very little difference in performance based on maturity, experience or age. The present study differed from that of Malina et al. (2005) in that this study sought to specifically separate out those participants who were going through their adolescent growth spurt in height. Where Malina et al., used stage of pubic hair development to compare groups based on sexual maturity, in this study maturity groups were defined by whether participants were within a year of their predicted age of PHV or not.

There was a plateau in performance between the Pre-PHV and PHV groups on the ball juggling task, while the Post-PHV performed substantially better than both the other groups. These results suggest that there is no change in performance during rapid growth but as growth slows there is potential to increase performance dramatically. However a factor which might have impacted this result is the type of training the soccer players in this study were doing. All three maturity groups were doing an average between 6 and 8 hours of soccer training/week and had been in organized soccer for an average of between 6 and 8 years. However the Post-PHV group was comprised entirely of soccer players from the high performance development group and while the Pre-PHV and PHV consisted of some players from the high performance group, the majority were from the local soccer team. According to their coaches the high performance development group's training includes a lot of ball juggling while the local team's training does not. This might partly explain the large difference of the post-PHV group from the other two maturity groups in results on the ball juggling task. However the participants in the Pre-PHV and PHV groups who were part of the same high performance development group as the post-PHV group performed similar to their peers in the same maturity category on the ball juggling task.

The differences in performance on the wall volley task between maturity groups did not mirror that of the ball juggling task. The range of performance across maturity groups was much smaller on the wall volley task than on the ball juggling task. The Post-PHV group did perform better than the Pre-PHV and PHV groups on the wall volley task, but not by nearly as much as on the ball juggling task. This may have been because the same task-specific training seen in the ball juggling amongst the players recruited from the high performance development centre was not true of the wall volley.

CHAPTER 5

5.0 Conclusion

Teenagers who are growing rapidly may be worse at placing their feet in space which may translate to increased clumsiness in everyday life. The results of the present study appears to show a plateau or decrease in adolescents' awareness of their body size in the year around the time of their peak growth spurt in stature (peak height velocity) and a significant improvement from the year around peak height velocity to 6 months or more after peak height velocity. The findings on the endpoint matching task mirrored those of performance on the soccer tasks. Adolescents within 6 months of their peak height velocity did not perform better, or even performed worse, than their peers who were more than 6 months before their predicted age at PHV. While those adolescents who were more than 6 months after their predicted age at PHV performed significantly better than those who were within a year of their predicted age at PHV. These findings suggest that a stage of adolescent awkwardness may exist and could be detected with a test of body size and movement awareness such as the endpoint matching task used in this study.

As children enter adolescence and start to grow rapidly it seems to take time for their brains to catch up to their bodies. Coaches, parents and athletes should be aware that during rapid growth children may lose sense of their body size and become clumsy. This information could be helpful for coaching adolescents. Adolescents who are in the middle of a rapid growth spurt shouldn't have their athletic potential judged based on performing skills that require good body awareness. Adolescents may benefit from performing skills which require them to relearn where their bodies are in space. Adolescents may need to practice skills and use their bodies to give their brain information about the size of their body and body segments to work with in order to adapt their body schemas to the changes that occur during rapid growth. Growing adolescents may benefit from being directed to look at where their limbs are in space with reference to the outside environment instead of relying on their body schema and proprioceptive feedback. Rather than simply watching a skill and then attempting to perform it they may benefit from being told to pay attention to where their limbs are.

5.1 Limitations

The endpoint matching task in this study was developed for this study and so there was no previous data to use to calculate power. The small sample size and particularly the small number of participants in the Pre-PHV ($n = 6$) and PHV ($n = 5$) groups was a limitation. There was a difference in type of training, particularly in ball juggling, between the high performance development group and the younger athletes from the local soccer team. Ball juggling, which was one of the soccer skills tested in this study, was included in the high performance development group's training but was not included as part of the local soccer team's training. Since the high performance group were also chronologically older it is possible that there was an age effect which may have contributed to the differences in soccer skill performance. The growth categories were chosen based on the accuracy of the APHV prediction equation, the actual ages during which the adolescent growth spurt affects teenagers' body awareness might not be ± 6 months around PHV. In addition the equation used for dividing participants into maturity groups has an

accuracy of ± 1 year 95% of the time, although the accuracy is highest when the measurements are done closest to the time of PHV (Mirwald et al., 2002). The participants in this study were all girls. There are large differences between boys and girls in terms of growth. On average boys hit PHV 2 years after girls and have a higher PHV, more growth per unit of time, than girls (Beunen & Malina, 1988; Malina et al., 2004; Tanner J. M., 1990). It could be expected for boys' internal body awareness to be more affected by their growth spurts than girls' because they have a greater rate of growth which would create a greater mismatch between the size their bodies used to be and the size they become, thus the mismatch between their body schema and new body size would also be greater, theoretically resulting in greater error on tasks which rely on body awareness.

5.2 Future directions

This is the first study that has examined the phenomenon of adolescent awkwardness using a measure of body schema and proprioception. The findings of this study suggest that adolescent awkwardness should be examined from that perspective rather than performance on motor tasks that rely on strength or speed. Participants were compared by maturity status based on a prediction of APHV, a longitudinal study with serial height measurements throughout adolescence would give a more reliable measure of when PHV occurs. This would also control for individual differences in body awareness.

It would be well worth conducting the study with a sample of boys or a larger mixed sample of boys and girls in order to compare performance of boys and girls on the tasks used in this study. Previous studies have shown a difference between girls and boys in measures of skill and coordination during adolescence (Thomas & French, 1985).

Future research on adolescent awkwardness could also compare early, average and late maturing adolescents and adolescents of different skill levels. A stage of adolescent awkwardness may particularly affect those youth, especially boys, who are growing the fastest (Visser et al., 1998) or those who are more skilled to begin with (Beunen & Malina, 1988; Visser et al., 1998). It is often the most rapidly growing youth, early maturers, who are selected for sports, particularly where strength and speed are assets (Sherar, Baxter-Jones, Faulkner, & Russell, 2007) because they are closer to their adult size and strength than their later maturing peers (Balyi et al., 2005; Lloyd & Oliver, 2012). Yet size and strength at a given chronological age during childhood does not equate to adult size, strength, motor performance (Balyi & Way, 2011; Beunen & Malina, 1988; Vizmanos, Martí-Henneberg, Clivillé, Moreno, & Fernandez-Ballart, 2001) or present sport specific skill (Figueiredo et al., 2011; Malina, et al., 2005).

REFERENCES

- Ali, A. (2011). Measuring soccer skill performance: a review. *Scandinavian journal of medicine & science in sports*, 21(2), 170-183.
- American Psychiatric Association. (1994). *Diagnostic and Statistical Manual of Mental disorders* (4th ed.). Washington, DC: American Psychiatric Association.
- Assaiante, C., Barlaam, F., Cignetti, F., & Vaugoyeau, M. (2014). Body schema building during childhood and adolescence: A neurosensory approach / Construction du schéma corporel au cours de l'enfance et de l'adolescence: une approche neurosensorielle. *Neurophysiologie Clinique / Clinical Neurophysiology*, 44(1), 3-12.
- Balyi, I., & Way, R. (2011). *The role of monitoring growth in long-term athlete development*. Retrieved 03 26, 2013, from Canadian Sport for Life: <http://www.canadiansportforlife.ca/>
- Balyi, I., Cardinal, C., Higgs, C., Norris, S., & Way, R. (2005). *Long-term athlete development: Canadian sport for life*. Vancouver: Canadian Sport Centres. Retrieved 2012
- Baumgartner, T. A., Jackson, A. S., Mahar, M. T., & Rowe, D. A. (2003). Evaluating skill achievement. In *Measurement for evaluation in physical education & exercise science* (7th ed., pp. 409-436). New York, NY, USA: McGraw-Hill.
- Baxter-Jones, A. D., Eisenmann, J. C., & Sherar, L. B. (2005). Controlling for maturation in pediatric exercise science. *Pediatric Exercise Science*, 17, 18-30.
- BBC. (2014). *Puberty: growth spurt*. Retrieved from BBC Science & Nature: <http://www.bbc.co.uk/science/humanbody/body/articles/lifecycle/teenagers/growth.shtml>
- Berlucchi, G., & Aglioti, S. (1997). The body in the brain: neural bases of corporeal awareness. *Trends in Neurosciences*, 20(12), 560-564.
- Beunen, G., & Malina, R. (1988). Growth and physical performance relative to the timing of the adolescent spurt. *Exercise & Sport Sciences Reviews*, 16(1), 503-540.
- Bielemann, R., Martinez-Mesa, J., & Gigante, D. P. (2013). Physical activity during life course and bone mass: a systematic review of methods and findings from cohort studies with young adults. *BMC musculoskeletal disorders*, 14(77).
- Brooker, R. J., Widmaier, E. P., Graham, L. E., & Stiling, P. D. (2008). Developmental genetics. In R. J. Brooker, E. P. Widmaier, L. E. Graham, & P. D. Stiling, *Biology* (p. 391). New York: McGraw-Hill.
- Bulk Rename Utility*. (2014, July). Retrieved from <http://www.bulkrenameutility.co.uk>
- Bulk Rename Utility 32-bit (Unicode). (2010). TGRMN Software. Retrieved from <http://www.bulkrenameutility.co.uk>

- Butterfield, S., Lehnhard, J., Lee, J., & Coladarci, T. (2004). Growth rates in running speed and vertical jumping by boys and girls ages 11-13. *Perceptual and motor skills*, 99(1), 225-234.
- Canadian Society of Exercise Physiology. (2013). *Physical activity training for health*. Canada: Canadian Society of Exercise Physiology.
- Carlson, T. A., Alvarez, G., Wu, D.-a., & Verstraten, F. A. (2010). Rapid assimilation of external objects into the body schema. *Psychological science*, 21(7), 1000-1005.
- Collins, R. D., & Hodges, P. B. (2001). Soccer. In *A comprehensive guide to sports skills tests and measurement* (pp. 199-211). Lanham, Maryland, USA: Scarecrow Press Inc.
- Davies, P., & Rose, J. (2000). Motor skills of typically developing adolescents: awkwardness or improvement? *Physical & Occupational Therapy in Pediatrics*, 20(1), 19-42.
- Dugdale, D. C. (2012, 3 9). *Aging changes in the bones - muscles - joints*. Retrieved 06 25, 2014, from MedLinePlus: <http://www.nlm.nih.gov/medlineplus/ency/article/004015.htm>
- Figueiredo, A., Coelho e Silva, M., & Malina, R. (2011). Predictors of functional capacity and skill in youth soccer players. *Scandinavian journal of medicine & science in sports*, 21(3), 446-454.
- Froberg, K., & Lammert, O. (1996). Development of muscle strength during childhood. In O. Bar-Or (Ed.), *The Child and Adolescent Athlete*. International Olympic Committee.
- Goble, D. (2010). Proprioceptive acuity assessment via joint position matching: from basic science to general practice. *Physical Therapy*, 90(8), 1176-1184.
- Hewett, T. E., Myer, G. D., & Ford, K. R. (2004). Decrease in neuromuscular control about the knee with maturation in female athletes. *The Journal of Bone and Joint Surgery*, 86-A(8), 1601-1607.
- IBM corporation. (n.d.). IBM SPSS Statistics (version 22). Retrieved from www.ibm.com
- Isaacs, L., Pohlman, R., & Hall, T. (2003). Vertical jump performance standards in children: an update. *Strategies: A Journal for Physical and Sport Educators*, 16(6), 33-35.
- Ivanenko, Y. P., Dominici, N., Daprati, E., Nico, D., Cappellini, G., & Lacquaniti, F. (2011). Locomotor body scheme. *Human Movement Science*, 30, 341-351.
- Ives, J. C. (2014). *Motor behavior: connecting mind and body for optimal performance*. Wolters Kluwer Health | Lippincott Williams & Wilkins.
- Jola, C., Davis, A., & Haggard, P. (2011). Proprioceptive integration and body representation: insights into dancers' expertise. *Exp Brain Res*, 257-265.
- Jones, D., & Round, J. (2000). Strength and muscle growth. In N. Armstrong, & W. van Mechelen (Eds.), *Paediatric Exercise Science and Medicine* (p. 139). New York: Oxford University Press.

- Khosla, S., Melton II, L. J., Dekutoski, M. B., Achenbach, S. J., Oberg, A. L., & Riggs, L. B. (2003). Incidence of childhood distal forearm fractures over 30 years. *The Journal of the American Medical Association*, 290(11), 1479-1485.
- Kirschenbaum, N., Riach, C., & Starkes, J. (2001). Non-linear development of postural control and strategy use in young children: a longitudinal study. *Experimental Brain Research*, 140(4), 420-431.
- Klavora, P. (2012). Human anatomy: the pieces of the body puzzle. In P. Klavora, *Biophysical Foundations of Kinesiology: Studying Human Movement and Health* (pp. 25-26). Kinesiology Books Publisher.
- Lattanzio, P.-J., & Petrella, R. (1998). Knee proprioception: A review of mechanisms, measurements, and implications of muscular fatigue. *Orthopedics*, 21(4), 463-472.
- List randomizer. (2015, January). Retrieved from Random.org: <https://www.random.org/lists/>
- Lloyd, R. S., & Oliver, J. L. (2012). The youth physical development model: A new approach to long-term athletic development. *Strength and Conditioning Journal*, 34(3), 61-72.
- Longo, M. R., & Haggard, P. (2010). An implicit body representation underlying human position sense. *Proceedings of the National Academy of Sciences of the United States of America*, 107(26), 11727-32. doi:10.1073/pnas.1003483107
- Malina, R. M., & Beunen, G. (1996). Monitoring of Growth and Maturation. In O. Bar-Or (Ed.), *The Child and Adolescent Athlete* (pp. 647-672). Oxford: International Olympic Committee.
- Malina, R. M., Cumming, S. P., Kontos, A. P., Eisenmann, J. C., Ribeiro, B., & Aroso, J. (2005). Maturity-associated variation in sport-specific skills of youth soccer players aged 13-15 years. *Journal of Sports Sciences*, 23(5), 512-522.
- Malina, R., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation, and physical activity* (2nd ed.). Windsor, Ontario, Canada: Human Kinetics.
- Mallau, S., Vaugoyeau, M., & Assaiante, C. (2010). Postural strategies and sensory integration: No turning point between childhood and adolescence. *PLoS ONE*, 5(9). doi:10.1371/journal.pone.0013078
- Maravita, A., & Iriki, A. (2004). Tools for the body (schema). *Trends in Cognitive Sciences*, 8(2), 79-86.
- Melzack, R. (1990). Phantom limbs and the concept of a neuromatrix. *Trends in Neurosciences*, 13(3), 88-92.
- Mirwald, R., Baxter-Jones, A., Bailey, D., & Beunen, G. (2002). An assessment of maturity from anthropometric measurements. *Physical Fitness and Performance*, 34(4), 689-694.

- Nottingham Post. (2012, 07 27). *Watch out for that bin as sudden growth spurts leave teenagers feeling clumsy*. Retrieved 02 25, 2014, from Nottingham Post: <http://www.nottinghampost.com/Watch-bin-sudden-growth-spurts-leave-teenagers/story-16602417-detail/story.html>
- Orr, D. P., & Ingersoll, G. M. (1988). Adolescent development: A biopsychosocial review. *Current Problems in Pediatrics*, 18(8), 447-499.
- Oxford English (UK) dictionary*. (2014). Retrieved 06 26, 2014, from Oxford University Press: <http://www.oxforddictionaries.com/definition/english/clumsy>
- Paillard, J. (1999). Body schema and body image: A double dissociation in deafferented patients. (G. Gantchev, & M. J. Massion, Eds.) *Motor Control, Today and Tomorrow*, 197-214.
- Payne, V. G., & Isaacs, L. D. (2002). *Human Motor Development: A Lifespan Approach* (5th ed.). Boston, MA: McGraw-Hill Publishers.
- Philippaerts, R., Vaeyens, R., Janssens, M., Van Renterghem, B., Matthys, D., Craen, R., . . . Malina, R. (2006). The relationship between peak height velocity and physical performance in youth soccer players. *Journal of Sports Sciences*, 24(3), 221-230.
- Physical Health and Education Canada. (2015). *What is physical literacy?* Retrieved October 25, 2012, from PHE Canada: <http://www.phecanada.ca/programs/physical-literacy/what-physical-literacy>
- Quatman, C. E., Ford, K. R., Myer, G. D., & Hewett, T. E. (n.d.). Maturation leads to gender differences in landing force and vertical jump performance: A longitudinal study.
- Quatman-Yates, C., Quatman, C., Meszaros, A., Paterno, M., & Hewett, T. (2012). A systematic review of sensorimotor function during adolescence: a developmental stage of increased motor awkwardness? *British Journal of Sports Medicine*, 46, 649-655. doi:10.1136/bjsm.2010.079616
- Rasband, W. (n.d.). ImageJ (version 1.48v). USA: National Institutes of Health. Retrieved from <http://imagj.nih.gov/ij>
- Reynolds, G. (2011, April 20). *Are gawky adolescents more injury prone?* Retrieved April 10, 2013, from The New York Times Health and Wellness: Well blog: <http://well.blogs.nytimes.com/2011/04/20/sports-injuries-and-the-teenage-brain/>
- Riemann, B., Myers, J., & Lephart, S. (2002). Sensorimotor system measurement techniques. *Journal of Athletic Training*, 37(1), 85-98.
- Rossetti, Y., Rode, G., Farnè, A., & Rossetti, A. (2005). Implicit body representations in action. In H. De Preester, & V. Knockaert (Eds.), *Body Image and Body Schema* (pp. 111-125). Amsterdam/Philadelphia: John Benjamins Publishing Company.
- Rowland, T. W. (2005). Growth and exercise. In T. W. Rowland, *Children's Exercise Physiology* (pp. 21-42). Human Kinetics.

- Saavedra, S., Woollacott, M., & van Donkelaar, P. (2007). Effects of postural support on eye hand Interactions across development. *Experimental Brain Research*, 180(3), 557-567.
- Scammon, R. E. (1930). *The measurement of man*. Minneapolis: University of Minnesota Press.
- Schuster, C. S., & Ashburn, S. S. (1992). *The process of human development: A holistic life-span approach*. New York: Lippincott.
- seca: medical measurement systems and scales. (n.d.). 40 Barn Street, Birmingham, United Kingdom. Retrieved from www.seca.com
- Sherar, L., Baxter-Jones, A., Faulkner, R., & Russell, K. (2007). Do physical maturity and birth date predict talent in male youth ice hockey players? *Journal of Sports Sciences*, 25(8), 879-886.
- Smith, T., Davies, L., & Hing, C. (2013). A systematic review to determine the reliability of knee joint position sense assessment measures. *The Knee*, 20(3), 162-169.
- Stamenov, M. (2005). Body schema, body image, and mirror neurons. In H. De Preester, & V. Knockaert (Eds.), *Body Image and Body Schema* (pp. 21-43). Amsterdam/Philadelphia: John Benjamins Publishing Company.
- Stillman, B. C., & McMeeken, J. M. (2001). The role of weightbearing in the clinical assessment of knee joint position sense. *The Australian Journal of Physiotherapy*, 47(4), 247-253.
- Streepey, J. W., & Angulo-Kinzler, R. M. (2002). The role of task difficulty in the control of dynamic balance in children and adults. *Human Movement Science*, 21(4), 423-438.
- Tanner, J. M. (1990). *Foetus into man: Physical growth from conception to maturity*. Cambridge, Massachusetts: Harvard University Press.
- Tanner, J. M., Whitehouse, R. H., Marubini, E., & Resele, L. F. (1976). The adolescent growth spurt of boys and girls of the Harpenden growth study. *Annals of Human Biology*, 3(2), 109-126.
- Tanner, J. M., Whitehouse, R. H., Marubini, E., & Resele, L. F. (1976). The adolescent growth spurt of boys and girls of the Harpenden growth study. *Annals of human biology*, 3(2), 109-126.
- Thomas, J. R., & French, K. E. (1985). Gender differences across age in motor performance : A meta-analysis. *Psychological Bulletin*, 98(2), 260-282.
- Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2008). Talent Identification and Development Programmes in Sport: Current Models and Future Directions. *Sports Medicine*, 38(9), 703-714.
- Vanderford, L., Meyers, M., Skelly, W., Stewart, C., & Hamilton, K. (2004). Physiological and sport-specific skill response of olympic youth soccer athletes. *Journal of Strength and Conditioning research*, 18(2), 334-342.

- Viel, S., Vaugoyeau, M., & Assaiante, C. (2009). Adolescence: A transient period of proprioceptive neglect in sensory integration of postural control. *Motor Control*, 13, 25-42.
- Visser, J., Geuze, R., & Kalverboer, A. (1998). The relationship between physical growth, the level of activity and the development of motor skills in adolescence: Differences between children with DCD and controls. *Human Movement Science*, 17, 573-608.
- Vizmanos, B., Martí-Henneberg, C., Clivillé, R., Moreno, A., & Fernandez-Ballart, J. (2001). Age of pubertal onset affects the intensity and duration of pubertal growth peak but not final height. *American Journal of Human Biology*, 13(3), 409-416.
- Williams, A. (2000). Perceptual skill in soccer : Implications for talent identification and development
Perceptual skill in soccer : Implications for talent identification and development. *Journal of Sports Sciences*, 18, 737-750.

APPENDIX A:
PARENT/GUARDIAN INFORMATION AND CONSENT FORM

College of Kinesiology, University of Saskatchewan
Parent/Guardian Information and Consent Form
Does Teenage Clumsiness Exist and Does It Influence Sports
Performance?

Principal Investigator (Supervisor)

Adam Baxter-Jones, University of Saskatchewan
E-mail: Baxter.jones@usask.ca
Phone: (306) 966-1078

Student Researcher

Emily van der Kamp, University of Saskatchewan
E-mail: Emily.vanderkamp@usask.ca
Phone: (306)-251-0011

Sponsor

Sport Canada and the Social Sciences and Humanities Research Council (SSHRC)
Phone: 613-992-0691

INTRODUCTION

Your child is invited to take part in this research study because they are a growing teenager and a soccer athlete. Your child's participation is voluntary; it is entirely up to them and you to decide if they will take part in this study. If they decide to participate they are still free to withdraw at any time and neither they nor you will have to give any reasons for that decision. If they do not wish to participate it will not affect their participation in soccer.

Please take time to read the following information carefully. You can ask the researchers to explain any information you do not understand or any questions you might have. Please feel free to discuss this with your family, friends or coach before deciding to allow your child to participate.

WHO IS CONDUCTING THE STUDY?

The study is being conducted by Emily van der Kamp for her Masters of Science in Kinesiology under the supervision of Dr. Adam Baxter-Jones. This research is being funded by SSHRC and Sport Canada. Neither the institution nor any of the investigators or staff will receive any direct financial benefit from conducting this study.

WHY IS THIS STUDY BEING DONE?

Most people are familiar with the idea that when teens hit their growth spurt they temporarily outgrow their own sense of their body's size and proportions and so appear to be very clumsy. However this phenomenon has been difficult to pinpoint in scientific studies. This study is taking a new approach to

studying teenage clumsiness. This is being done by looking at where a person is at in their growth and how they use their body and brain's information about their body's size and proportions as well as sensory feedback about limb movement and position.

WHO CAN PARTICIPATE IN THE STUDY?

Your child is eligible to participate in this study if they are a youth soccer player between the ages of 10-14 (girls) or 12-16 (boys) with no history of a motor coordination disorder. The reason for the different ages between boys and girls is that girls hit their growth spurt earlier than boys.

WHAT DOES THE STUDY INVOLVE?

We will measure your child's standing height, sitting height and weight to calculate how close they are to their largest teenage growth spurt. Then they will do two soccer skills tasks (ball juggling and wall volley) and a foot endpoint matching task. The study will be conducted during soccer practice at the soccer centre but on a separate field from regular practice. It will take 20 minutes.

The endpoint matching task involves putting your foot at a particular position and then trying to match it both while you can see your foot and with eyes closed. Photographs will be taken to digitally compare where your child's foot was and how close they were to matching that position. The point of this task is to measure your child's sense of where their feet are in space and to see if this is affected by the teenage growth spurt. The soccer skills tasks are ball juggling and a wall volley, the point is to see if the teenage growth spurt affects soccer performance.

Height and weight measurements are used to figure out where your child is at in your growth spurt. Standing height and sitting height are both measured and leg length is calculated. Your child's age, body weight, leg length and sitting height all go into an equation to calculate if they have hit your peak growth rate in height.

The questionnaire is to determine how many years your child has been in sport, how many years they have played soccer specifically and what their training has been like, as well as if they are right or left footed. Your child can refuse to answer any questions they are not comfortable with.

As a participant your child's data will be assigned a random number and they won't be able to be identified from the photos taken.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY

If your child chooses to participate in this study they will not receive any direct benefits. It is hoped the information gained from this study can be used in the future to benefit other young athletes.

ARE THERE POSSIBLE RISKS AND DISCOMFORTS?

There are no potential risks or discomforts associated with participating in this study.

WHAT HAPPENS IF I DECIDE TO WITHDRAW?

Your child's participation in this research is voluntary. They may withdraw from this study at any time. They do not have to provide a reason. Your child's participation in soccer will not be affected.

If your child chooses to enter the study and then decides to withdraw at a later time, all data already collected from them during their enrolment will be retained for analysis.

WHAT WILL THE STUDY COST ME?

You will not be charged for any research-related procedures. Your child will not be paid for participating in this study. Your child will not receive any financial benefits for being in this study, or as a result of data obtained from research conducted under this study.

WILL MY PARTICIPATION BE KEPT CONFIDENTIAL?

Your child's individual results will not be given to their coach. Your child's name will not be attached to any information, nor mentioned in any study report, nor be made available to anyone except the research team. It is the intention of the research team to publish results of this research in scientific journals and to present the findings at related conferences and workshops, but your child's identity will not be revealed.

WHO DO I CONTACT IF I HAVE QUESTIONS ABOUT THE STUDY?

If you have any questions or desire further information about this study before or during participation, you can contact Emily van der Kamp at 306-251-0011.

If you have any concerns about your child's rights as a research participant and/or their experiences while participating in this study, contact the Chair of the University of Saskatchewan Research Ethics Board, at 306-966-2975 (*out of town calls 1-888-966-2975*). The Research Ethics Board is a group of individuals (scientists, physicians, ethicists, lawyers and members of the community) that provide an independent review of human research studies. This study has been reviewed and approved on ethical grounds by the University of Saskatchewan Research Ethics Board.

College of Kinesiology, University of Saskatchewan
CONSENT TO PARTICIPATE

PLEASE SIGN THIS FORM AND RETURN TO EMILY VAN DER KAMP: Emily.vanderkamp@usask.ca
OR send Emily an e-mail stating: "I consent for my child (your child's name here) to participate in the
Teenage Clumsiness study."

Study Title: Does teenage clumsiness exist and does it influence sports performance?

- I have read or have had this read to me and understand the research participant information and consent form.
- I have had sufficient time to consider the information provided, including the risks and benefits of participation and to ask for advice if necessary.
- I have had the opportunity to ask questions and have had satisfactory responses to my questions.
- I understand that my child's participation in this study is voluntary and that I am completely free to choose not to participate or to withdraw from this study at any time without changing in any way the quality of care or coaching that my child receives.
- I understand that I am not waiving any of my legal rights as a result of signing this consent form.
- I will receive a dated and signed copy of this form.

I agree for my child to participate in this study:

CONSENT SIGNATURE OF PARENT / LEGAL GUARDIAN

DATE (DD/MMM/YYYY)

STATEMENT OF PERSON EXPLAINING CONSENT

I have explained to the participant and their parent/legal guardian the nature and purpose of the above study. The participant and their parent/legal guardian signing this form have been given enough time to review the information. There has been an opportunity to ask questions and receive answers regarding the nature, risks and benefits of participation in this research study. The participant and their parent/legal guardian appear to understand the nature and purpose of the study and the demands required of participation.

SIGNATURE OF PERSON
CONDUCTING CONSENT

DATE (DD/MMM/YYYY)

PRINTED NAME OF PERSON
CONDUCTING CONSENT

APPENDIX B:
PARTICIPANT INFORMATION AND ASSENT FORM

College of Kinesiology, University of Saskatchewan

Participant Information and Assent Form

***Does teenage clumsiness exist and does it influence sports
performance?***

Principal Investigator (Supervisor)

Adam Baxter-Jones, University of Saskatchewan

E-mail: Baxter.jones@usask.ca

Phone: (306) 966-1078

Student Researcher

Emily van der Kamp, University of Saskatchewan

E-mail: Emily.vanderkamp@usask.ca

Phone: (306)-251-0011

Sponsor

Sport Canada and the Social Sciences and Humanities Research Council (SSHRC)

Phone: 613-992-0691

INTRODUCTION

You can choose to take part in this research study because you are a youth soccer athlete.

Please read this information about the study before you decide if you want to do it. You can ask the researchers any questions you think of. You can also talk to your family, friends or coach before you decide if you want to be in this study.

WHO IS CONDUCTING THE STUDY?

The researcher doing this study is Emily van der Kamp. This research is paid for by SSHRC and Sport Canada. No one is being paid to do this study.

WHY IS THIS STUDY BEING DONE?

When teenagers hit their growth spurt they sometimes don't seem to know how much their arms and legs have grown and become more clumsy than before. This hasn't been easy to show with research. This study is looking at teenage clumsiness in a new way by comparing where a person is at in their growth with what information their brain uses about their body's movement and size.

WHO CAN PARTICIPATE IN THE STUDY?

You can be in this study if you are a youth soccer player aged 10-14 years (if you are a girl) or 12-16 years (if you are a boy). The reason for the different ages between boys and girls is that girls hit their growth spurt earlier than boys

WHAT DOES THE STUDY INVOLVE?

Taking part in this study involves 3 motor control tasks, height and weight measurements and a questionnaire. It takes about 20 minutes.

The motor tasks are an 'endpoint matching task' with your feet and two soccer skills tasks (ball juggling and wall volley). The 'endpoint matching task' involves putting your foot at a particular position (the endpoint) and then trying to put it in the same position with your eyes closed. Photos will be taken of your foot when you do this task to see how close you were to matching the endpoint position. The point of this task is to see if you can tell how far in front of you your foot is when you can't see it. The soccer skills tasks are ball juggling and a wall volley, the point is to see if what happens to a person's soccer skills while they are growing a lot compared to when they are not growing as quickly.

Height and weight measurements are used to figure out where you are at in your growth spurt. Your age, body weight, leg length and sitting height all go into an equation to calculate if you've hit your biggest growth spurt.

The questionnaire is about how many years you've been in sport, how many years you've played soccer specifically and what your training has been like, as well as if you are right or left footed. You can choose not to answer any of the questions if you don't like them.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY

There are no direct benefits to participating in this study. It is hoped the information gained from this study can be used to benefit other young athletes in the future.

ARE THERE POSSIBLE RISKS AND DISCOMFORTS?

There are no potential risks or discomforts associated with participating in this study.

WHAT HAPPENS IF I DECIDE TO WITHDRAW?

You can choose to stop participating in this study at any time with no consequences. If you decide to withdraw you don't have to give any reason why.

If you choose to participate in this study and then decide to quit later, your data and results from when you were participating will still be used in the study.

WHAT WILL THE STUDY COST ME?

Participating in this study will not cost you anything, you won't be paid for participating either.

WILL MY PARTICIPATION BE KEPT CONFIDENTIAL?

Your results will not be given to your coach or your parents. Your results will be combined with everyone else's results so that nobody can tell what any participant's individual results were. The researchers are more interested in the average of everyone's results.

You will not be able to be identified from the photos taken.

WHO DO I CONTACT IF I HAVE QUESTIONS ABOUT THE STUDY?

If you have any questions about this study before or during participation, you can contact Emily van der Kamp at 306-251-0011.

If you have any concerns about your rights as a research participant and/or your experiences while participating in this study, contact the Chair of the University of Saskatchewan Research Ethics Board, at 306-966-2975 (*out of town calls 1-888-966-2975*). The Research Ethics Board is a group of individuals (scientists, physicians, ethicists, lawyers and members of the community) that provide an independent review of human research studies. This study has been reviewed and approved on ethical grounds by the University of Saskatchewan Research Ethics Board.

College of Kinesiology, University of Saskatchewan
CONSENT TO PARTICIPATE

Study Title: Does teenage clumsiness exist and does it influence sports performance?

- I have read or have had this read to me and understand the research participant information and consent form.
- I have had sufficient time to consider the information provided, including the risks and benefits of participation and to ask for advice if necessary.
- I have had the opportunity to ask questions and have had satisfactory responses to my questions.
- I understand that my participation in this study is voluntary and that I am completely free to choose not to participate or to withdraw from this study at any time without changing in any way the quality of care that I receive.
- I understand that I am not waiving any of my legal rights as a result of signing this consent form.
- I will receive a dated and signed copy of this form.

I agree to participate in this study:

PRINTED NAME OF PARTICIPANT

SIGNATURE OF ASSENTING PARTICIPANT

STATEMENT OF PERSON EXPLAINING CONSENT

I have explained to the participant and their parent/legal guardian the nature and purpose of the above study. The participant and their parent/legal guardian signing this form have been given enough time to review the information. There has been an opportunity to ask questions and receive answers regarding the nature, risks and benefits of participation in this research study. The participant and their parent/legal guardian appear to understand the nature and purpose of the study and the demands required of participation.

SIGNATURE OF PERSON
CONDUCTING CONSENT

DATE (DD/MMM/YYYY)

PRINTED NAME OF PERSON
CONDUCTING CONSENT

APPENDIX C:
DATA COLLECTION FORM

Teenage clumsiness data collection form

Participant name: _____

☐ Participant assent signed

☐ Parental consent signed

☐ Questionnaire filled out

Birthdate (day/month/year): _____

Anthropometric measurements:

Height* (cm):

Weight* (kg):

Sitting height* (cm):

**3rd measurement only if first 2 differ by more than 0.5cm or 0.1kg*

Soccer ball tasks:

Wall volley (number of rebounds in 30s):

Juggling (number of taps in 30s):

APPENDIX D:
QUESTIONNAIRE

Teenage Clumsiness Research Questionnaire

Footedness:

Which foot do you prefer to kick a soccer ball with?

Training history:

How long have you been participating in organized soccer?

How many hours of soccer training do you do per week?

How many hours of training (not just soccer) do you do per week?

What other sports (not including soccer) have you been in and for how long (what ages were you when you participated)?